VOLUME XXXVI NUMBER 6 WHOLE NUMBER 315

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

EDITOR, C. A. CHANT ASSISTANT EDITOR, F. S. HOGG
David Dunlap Observatory
Richmond Hill P.O., Ont.

ASSOCIATE EDITORS
R. MELDRUM STEWART
Dominion Astronomer
Ottawa

J. A. PEARCE
Head Astronomer
Dominion Astrophysical Observatory
Victoria, B.C.

J. PATTERSON
Controller of the Meteorological Service of Canada, Toronto

PUBLISHED MONTHLY
(Ten numbers per year)

July-August, 1942

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

VOL. XXXVI, No. 6 JULY-AUGUST, 1942 WHOLE No. 315

Articles PAGE

The Frequency-Distribution through the Year of Abnormally High and Low Daily Mean Temperatures at Toronto ..... *Richmond W. Longley* 225

Does Anything Ever Happen on the Moon? (with Plates XI to XV) ..... *Walter H. Haas* 237

Report of the Dominion Astrophysical Observatory, Victoria, B.C., for the Years 1940 and 1941 (with Plate XVI) ..... *J. A. Pearce* 273

Review of Publications

Publications of the University of Pennsylvania—Astronomical Series (*F.S.H.*)—Books on the Weather for Amateurs (*Alvin Thiessen*) 288

Notes and Queries

Help, instead of Hindrance from a Difficulty ..... *J. W. Campbell* 291

Meetings of the Society

At Toronto—At Ottawa 292

Upon request, made previous to publication of article, contributors will be supplied free with twenty-five copies of the sheets containing the article attached to a printed cover.

Extra copies about as follows:

	4 pp.	8 pp.	12 pp.	16 pp.	20 pp.	24 pp.
50 copies....	$3 50	$5 50	$9 50	$10 00	$13 00	$16 00
100 copies....	4 00	7 00	10 00	11 00	14 00	18 00
200 copies....	4 50	8 00	11 00	12 00	15 50	20 00

Covers, extra. 50 copies, $1.50; 100 copies, $2.00; 200 copies, $2.50.

Address of Editors: David Dunlap Observatory, Richmond Hill, Ont.

Business correspondence, remittances, etc., should be addressed to J. H. Horning, Treasurer of the Society, 198 College Street, Toronto.

$2.00 per annum. Single numbers, 25 cents.

Subscription to the JOURNAL is included in membership fee.

Visitors to Toronto who wish to get in touch with the Society are invited to telephone:

General Secretary—Mr. E. J. A. Kennedy, EL. 4419.
Assistant Secretary—Miss E. M. Budd, RA. 7186.
Chairman of Toronto Centre—Rev. Dr. D. W. Best, LL. 0555.

For Sale—Very good 8-in. aluminized plate glass 70% paraboloid mirror, 71-in. f.l., price $45, or with cell and diagonal, $50. Apply to H. M. Johnson, 126 Albemarle St., Rochester, N.Y.

PRINTED IN CANADA

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY
OF CANADA

Vol. XXXVI, No. 6 JULY-AUGUST, 1942 WHOLE No. 315

THE FREQUENCY-DISTRIBUTION THROUGH THE YEAR OF ABNORMALLY HIGH AND LOW DAILY MEAN TEMPERATURES AT TORONTO*

By RICHMOND W. LONGLEY

SUMMARY

This paper presents the results of an analysis of the mean temperatures recorded at Toronto during the century 1841-1940, which was undertaken to discover the frequency of abnormally low and abnormally high mean temperatures. Tables giving these frequencies by months and also by five-day periods called *pentads* are presented, and the results are compared with those presented by Hawke[3] in a similar analysis of temperatures at Greenwich, England. It is found that, with its greater variability of temperatures, Toronto had slightly more than twice as many days 10 Fahrenheit degrees or more away from normal than Greenwich had. But the increase in the number of days 20 degrees or more from normal was 35-fold. It is also shown that the standard deviation of daily mean temperatures is almost twice as great in winter as in summer, being 10.50 Fahrenheit degrees in February compared with 5.29 in August. It is further shown that the change to and from the increased variability found during the winter months is not gradual, but takes place relatively suddenly during the last half of November and the middle weeks of March. Reasons are advanced for the facts brought to light.

The report of Hawke[3] on the days with abnormal temperatures at Greenwich aroused the curiosity of the author concerning the difference that there would be between Greenwich and some other locality, and especially one under a different climatic régime. Toronto was chosen as a suitable alternate location, and an analysis of the temperatures at Toronto was undertaken, following much the same methods as those used by Hawke. Daily temperatures have been taken at Toronto since March 1840. But, in order to include a round

*Published by permission of J. Patterson, Controller, Meteorological Service of Canada. The references are at the end of the article.

number of years, the period of study was restricted to the 100 years from January 1841 to December 1940.

The figures used were those of the maximum and minimum temperatures at Toronto, kept on the files at the Meteorological Office at Toronto.[4] The mean temperature was computed as the average of these two temperatures. During the course of the hundred years there has been a lack of uniformity in these observations. There have been changes in the thermometers used. Also there have been two changes in the location of the thermometers, and there has been an increase in the urbanization of the surroundings. These factors might prevent the series from being strictly uniform. Yet the use of the average of the maximum and minimum for the mean, and the possible slight lack of uniformity do not appreciably diminish the significance of the results.

The figures used are given to the nearest tenth of a degree, Fahrenheit. Since it was necessary to use these fractions in the computations, the boundaries of each class were defined to the nearest tenth of a degree. Thus days more than 10° below normal would include those 10.1° below normal. Hawke's limit, corresponding to the present limit 10, would be 9.5° below normal, since he worked to the nearest degree Fahrenheit. For this reason, the figures are not strictly comparable. However, in spite of these differences, which are only small, the results obtained in the two investigations have been directly compared. There is no indication that serious discrepancies in the comparison result from this procedure. In addition, comparable figures were finally obtained. The normal was taken as a smoothed curve through the monthly means for the century under study.

The figures obtained are found grouped by months in Table I, and grouped by five-day periods, with the data for February 29 excluded, in Table II.

To save space in referring to these days with abnormal temperatures, the following abbreviations are used:

(a) days more than 20° above normal, *ew* (i.e., exceedingly warm).
(b) days more than 15° above normal, *vw* (i.e., very warm).
(c) days more than 10° above normal, *w* (i.e., warm).
(d) days more than 10° below normal, *c* (i.e., cold).
(e) days more than 15° below normal, *vc* (i.e., very cold).
(f) days more than 20° below normal, *ec* (i.e., exceedingly cold).

TABLE I

DISTRIBUTION BY MONTHS OF DAYS AT TORONTO WITH ABNORMALLY HIGH AND LOW TEMPERATURES, PERIOD 1841-1940

Month	*ew* days	*vw* days	*w* days	*c* days	*vc* days	*ec* days
January	24	148	535	574	284	114
February	15	90	406	515	253	110
March	20	92	306	436	173	60
April	18	81	236	194	30	3
May	12	63	260	149	18	1
June	3	40	195	109	9	1
July	4	27	153	74	6	–
August	1	12	123	61	–	–
September	2	54	255	168	10	1
October	4	57	278	226	18	–
November	3	59	233	251	72	17
December	9	71	358	520	238	91
TOTALS	115	794	3,338	3,277	1,111	398

The abbreviations for classes (b), (c), (d), and (e) are those used by Hawke. The classes (a) and (f) were necessary because of the larger number of these days occurring in Toronto than in Greenwich. Group (a) is included in group (b), and both of these are included in group (c); similarly group (f) is included in group (e), and both included in group (d).

Table III gives the monthly distribution of Greenwich abnormal days. The data are from Hawke. Fig. 1 presents a graph of the distribution of the *c* and *w* days by pentads at Toronto.

As was to be expected, the number of abnormal days was much greater for Toronto than for Greenwich. In Toronto, the average number of days per year more than 10° from normal is 66, equally divided between *w* and *c* days. For Greenwich, the average numbers of the *w* and *c* days per year are 17.5 and 11 respectively. Days in the *vw* and *vc* categories average in Toronto 8 and 11 per year respectively, while corresponding figures for Greenwich are 0.7 and 1.3 days per year. For Greenwich, Hawke found only 15 days that were 20° or more away from normal in 96 years, 1 being an *ew* day, and 14 being *ec* days, thus averaging about one day in six years. Toronto averages 1 *ew* and 4 *ec* days a year. The maximum divergence from normal found at Greenwich was 25°. At Toronto

TABLE II

DISTRIBUTION BY PENTADS OF DAYS WITH ABNORMAL TEMPERATURES AT TORONTO, 1841-1940

Central day of pentad	*ew* days	*vw* days	*w* days	*c* days	*vc* days	*ec* days
January 3	2	24	82	100	48	20
January 8	4	22	84	81	44	19
January 13	3	15	75	85	44	19
January 18	2	27	88	104	47	14
January 23	9	30	94	86	46	21
January 28	3	25	98	105	51	20
February 2	2	15	55	95	44	19
February 7	5	16	76	93	39	27
February 12	3	22	92	96	48	18
February 17	2	16	63	86	51	17
February 22	4	20	81	83	37	17
February 27	–	7	59	80	40	14
March 4	1	15	57	98	41	16
March 9	2	15	48	61	22	4
March 14	4	10	57	76	31	7
March 19	3	21	54	80	34	18
March 24	6	19	44	63	31	9
March 29	4	11	37	45	10	4
April 3	3	15	40	52	11	–
April 8	6	16	38	29	3	–
April 13	1	12	32	32	2	1
April 18	3	13	45	34	9	–
April 23	1	15	43	28	3	2
April 28	4	10	38	19	2	–
May 3	2	14	44	25	3	–
May 8	5	19	60	16	2	–
May 13	2	7	29	23	3	–
May 18	–	7	36	27	3	–
May 23	1	5	39	26	2	–
May 28	1	9	41	28	5	1
June 2	3	16	44	18	3	–
June 7	1	10	41	26	1	–
June 12	–	3	19	25	3	1
June 17	–	7	25	19	2	–
June 22	–	1	33	20	–	–

TABLE II—*continued*

Central day of pentad	*ew days*	*vw days*	*w days*	*c days*	*vc days*	*cc days*
June 27	–	5	39	3	–	–
July 2	2	8	41	12	–	–
July 7	1	8	42	2	–	–
July 12	1	6	27	9	1	–
July 17	–	1	19	23	2	–
July 22	–	–	8	13	–	–
July 27	–	–	13	11	1	–
August 1	–	5	12	20	2	–
August 6	–	4	20	7	–	–
August 11	–	2	21	3	–	–
August 16	–	–	15	10	–	–
August 21	1	3	27	7	–	–
August 26	–	–	20	14	–	–
August 31	1	7	38	10	–	–
September 5	–	9	42	6	–	–
September 10	–	10	51	19	3	–
September 15	1	8	39	37	3	–
September 20	–	8	41	37	2	1
September 25	–	11	42	37	1	–
September 30	–	5	33	41	2	–
October 5	1	15	54	29	3	–
October 10	1	14	43	36	2	–
October 15	–	8	48	33	–	–
October 20	2	8	42	35	2	–
October 25	–	4	37	45	8	–
October 30	–	9	50	37	2	–
November 4	–	5	36	30	5	–
November 9	–	7	38	27	1	–
November 14	–	7	34	35	9	2
November 19	1	16	50	42	7	2
November 24	2	12	31	51	17	5
November 29	–	13	39	83	41	11
December 4	–	6	40	79	26	9
December 9	3	14	56	79	37	11
December 14	1	13	60	94	44	14
December 19	1	8	53	80	39	19
December 24	2	11	74	94	44	16
December 29	2	15	69	75	40	19
TOTALS	115	794	3,335	3,269	1,109	397

TABLE III

DISTRIBUTION BY MONTHS OF DAYS AT GREENWICH, ENGLAND, WITH ABNORMALLY HIGH AND LOW TEMPERATURES, PERIOD 1841-1936 (FROM HAWKE)

Month	*vw days*	*w days*	*c days*	*vc days*
January	7	279	175	31
February	1	161	178	32
March	1	109	133	9
April	11	103	40	–
May	11	99	82	–
June	3	90	37	–
July	5	91	20	–
August	12	82	3	–
September	7	69	17	–
October	1	138	67	–
November	–	172	104	8
December	12	283	205	40
TOTALS	71	1,676	1,061	120

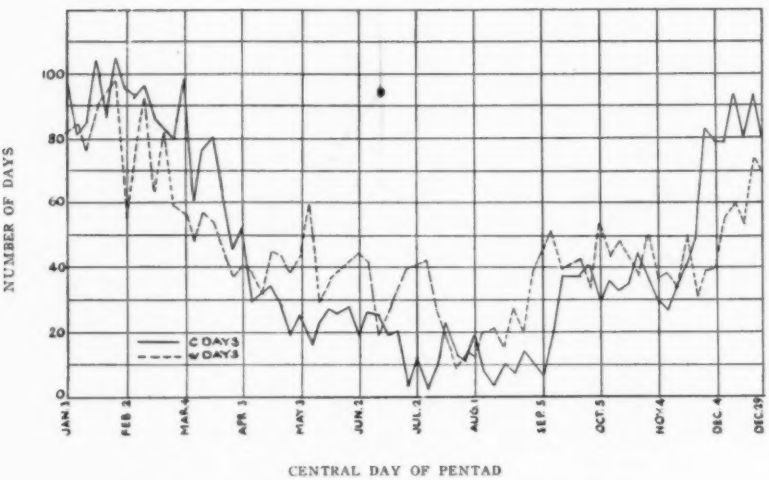


FIG. 1.—Distribution of *w* and *c* days by pentads at Toronto, 1841-1940.

the maximum divergence above normal was 27°, but there were 13 days in the 100 years which were 25° or more above normal. Days exceptionally colder than normal were more frequent, with 37 days during the period which were 30° or more colder than normal. The extremes were recorded on January 22, 1857, mean temperature −16°, which is 38° below normal, and on February 8, 1934, mean temperature −17°, which is 38° below normal. All the days which were 30° or more below normal occurred in the winter season, with the earliest on November 30 and the latest on March 17.

Buchan[2] postulated that there is a tendency for cold periods or warm periods to recur at the same time of the year, and determined a number of these "Buchan periods" for Scotland. Hawke[3] showed that, on the basis of his own investigation of a 96-year period, there is no evidence that during these "Buchan periods" the number of *w* days or *c* days was significantly greater than during days near the same time of year.

If there are Buchan periods at Toronto, it does not follow that these occur on the same dates that Buchan discovered for Scotland. Such periods should be in evidence, as postulated by Hawke, by the larger number of *w* or *c* days occurring on those dates during an extended period. In the present study, the records for the first fifty years were kept separate from those of the second fifty years. The data for the first fifty years were studied to discover periods of relative maxima of *w* days or *c* days. The frequencies on these dates for the second fifty years were then compared with the frequencies on other days at the same time of the year. But there was no evidence that times of relative maxima during the first half of the period continued to give a larger number of *w* days or *c* days during the second half-period. Thus the study obtained no evidence of the occurrence of Buchan periods at Toronto.

A study was made also of the variation throughout the year of the variability of the mean temperatures throughout the century by means of the standard deviations. The standard deviation, if the frequency distribution is normal, is a measure of the spread of the distribution. Two-thirds of the observations should be found within a range equal to the standard deviation on either side of the mean. As shown by the figures in Table I, there is a tendency during the months from November to March to have more *c* days than *w* days,

while during the other seven months the tendency is reversed. Hence the frequency distributions will deviate slightly from normal. Nevertheless the values of the standard deviation will give an approximate measure of the change in variability. These were computed for the 13th and the 28th of each month. The values of these, with their standard errors, are found in Table IV.

TABLE IV

STANDARD DEVIATIONS OF THE MEAN TEMPERATURES OBSRRVED AT TORONTO ON THE SAME DATE DURING THE PERIOD 1841-1940, WITH THEIR STANDARD ERRORS

Date	*Standard deviation and standard error*	*Date*	*Standard deviation and standard error*
January 13	10.07 ± .72	July 13	5.74 ± .41
January 28	9.66 ± .69	July 28	5.73 ± .41
February 13	11.41 ± .81	August 13	4.99 ± .36
February 28	9.51 ± .68	August 28	5.46 ± .39
March 13	8.72 ± .62	September 13	6.34 ± .45
March 28	7.33 ± .52	September 28	6.92 ± .49
April 13	6.66 ± .48	October 13	6.57 ± .47
April 28	6.85 ± .49	October 28	6.69 ± .48
May 13	6.37 ± .46	November 13	5.82 ± .41
May 28	6.42 ± .47	November 28	8.11 ± .58
June 13	5.72 ± .41	December 13	10.55 ± .75
June 28	5.00 ± .36	December 28	9.77 ± .70

On the assumption of a normal frequency distribution, and with a value of the standard deviation for the distribution, a calculation can be made of the number of occurrences that will deviate from the normal by any given amount. Thus it is possible to calculate the number of days in January which would be 10° or more away from normal if a value for the standard deviation is taken. This was done for each month, the standard deviations used being weighted means of the standard deviations for the 13th and 28th of the month and of the 28th of the preceding month. This was done also for a deviation of 20° from normal when the standard deviation was large. Table V presents these values. The agreement of the calculated values with the observed values is not perfect, but except for January the variation is within the range that would be obtained if the standard deviation

were at one time increased, and the second time diminished by its standard error. These values, then, can be a measure of the deviation that can be expected during any particular month. For example it can be stated that during a normal month of May, two-thirds of the days will lie within 6.5° of normal, and the theoretical relative fre-

TABLE V

COMPARISON OF THE OBSERVED NUMBER BY MONTHS OF DAYS WITH ABNORMAL TEMPERATURES WITH THE NUMBER COMPUTED BY MEANS OF THE STANDARD DEVIATION, TORONTO, 1841-1940

Month	*Standard deviation*	*Total w and c days calculated*	*Total w and c days observed*	*Total ew and ec days calculated*	*Total ew and ec days observed*
January	9.89	967	1109	134	138
February	10.50	955	922	159	125
March	8.57	754	745	61	80
April	6.88	439	425	11	21
May	6.50	384	409	—	—
June	5.72	242	274	—	—
July	5.55	222	226	—	—
August	5.29	182	184	—	—
September	6.27	332	423	—	—
October	6.69	418	504	9	4
November	6.61	391	484	—	—
December	9.75	946	878	125	100

quency of a day which is, say, 12° away from normal can be calculated.

The reverse of the above calculation can be made also. Thus, given the number of items in a frequency distribution, and the number of items that diverge from the mean by some given value, and assuming that the distribution is normal, then an approximate value for the standard deviation may be obtained. Lacking the original data for Greenwich, this was done from the data given by Hawke. The values thus obtained for the standard deviation for each month are given in Table VI.

The differences noted between temperatures at Greenwich and Toronto are due, of course, to their relative geographical locations. Greenwich has not always maritime weather. Occasionally an

easterly wind brings over Great Britain a continental air mass, bringing to Greenwich a taste of continental weather. But, even in this situation, the air is somewhat modified by its passage over the North Sea. Generally, though, the Greenwich temperature is controlled by air that has been over the waters of the northwestern Atlantic for

TABLE VI

STANDARD DEVIATIONS, BY MONTHS, OF THE MEAN TEMPERATURES OBSERVED AT GREENWICH, ENGLAND, DURING THE PERIOD 1841-1936

Month	*Standard deviation*	*Month*	*Standard deviation*
January	6.6	July	4.6
February	6.2	August	4.3
March	5.5	September	4.4
April	4.8	October	5.2
May	5.0	November	5.7
June	4.7	December	6.8

considerable periods. And since, relative to land temperatures, the temperature of the water varies little from year to year, and the horizontal temperature gradient is small, the temperatures for any given calendar day at Greenwich are moderately constant throughout a century. Toronto, on the other hand, is not completely continental in its climatic characteristics, since the temperature at Toronto is frequently affected by its proximity to the Great Lakes. The predominating character of the weather is also modified at times by the previous passage of the air over Hudson Bay, and by the presence of air that has been brought from the Gulf of Mexico by a southerly wind. But these only modify the greater variability of climate that is found in continental regions. Taking the standard deviations as a basis for judgment, it is seen that in summer the difference in variability between the two locations is not great, although even at this time Toronto temperatures are slightly more variable than those of Greenwich. But during the months from November to March the difference is more marked. The standard deviations of Toronto temperatures then are about one-and-one-half times as great as those for Greenwich.

A study of the curve for the number of *c* days by pentads for Toronto shows that there is not a smooth change from the low number of *c* days found in the summer months to the large number of *c* days found during the winter. Instead there is an increase about the first week of September, then a levelling off with another sudden increase about the fourth pentad in November. The break in the spring is not quite as pronounced, but does appear in the drop in the number of *c* days near the end of March. Similar, but not so pronounced, changes in the number of *w* days occur during March and during the first half of December. This period of increased variability found in the winter season is coincident with the period during which the exceptionally cold days occur, that is between November 30 and March 17. The same increase of variability is also revealed in the values of the standard deviation for the same period, as computed for the selected 24 days of the year.

An explanation for this fact is found in the geographical location of Toronto. During the middle of the month of November, the regions of northern Quebec and Ontario have received a winter blanket of snow. Owing to the low insolation and the reflection of heat rays caused by the snow cover, these areas will not supply heat to air transported over them. The winter type of Polar Continental air which has been formed in its source region to the northwest and north will not, then, be modified as it passes over these regions to reach southern Ontario. Outbreaks of this air mass give Toronto its extremely cold spells during the whole of the winter season, beginning some time during the last half of November and continuing until the middle of March. This relatively rapid decrease in temperature to the north of Toronto during the late autumn is shown by the mean monthly isotherms for North America. According to the maps published by Brooks and Connor,[1] the range in mean isotherms found within 500 miles of Toronto changes from 20 Fahrenheit degrees in September to 25 Fahrenheit degrees in November and to 43 Fahrenheit degrees in January. Thus the southward extension of the snow cover is followed by an increase in the temperature gradient, and so a greater probability of extreme temperatures through the advection of air.

The author wishes to take this opportunity to acknowledge the assistance of Mr. M. M. Monsinger of the Toronto staff of the Meteorological Service of Canada in his cooperation in the study by supplying him with the data used.

Metrorological Office,
Toronto.

REFERENCES

[1]Brooks, C. E., and A. J. Connor. Climatic maps of North America. Maps 1-6. Harvard University Press, Cambridge, Mass., 1936.

[2]Buchan, A. Interruptions in the regular rise and fall of temperatures in the course of the year. *J. Scot. Met. Soc.*, n.s. vol. 2, pp. 4-16, 1869.

[3]Hawke, E. L. The frequency distribution through the year of abnormally high and low daily mean temperatures at Greenwich Observatory. *Quart. J. R. Met. Soc.*, vol. 67, pp. 247-256, 1941.

[4]Temperatures at Toronto Meteorological Observatory (unpublished data), Meteorological Office, Toronto.

DOES ANYTHING EVER HAPPEN ON THE MOON?

By Walter H. Haas

(With five Plates)

Introduction

Contents

Introduction—Some fundamental ideas—The Observers—Observational procedure—Methods of investigation—Drawings and descriptions (objects arranged alphabetically)—Some observations of colours on the moon—Colour studies by our group (objects arranged alphabetically)—Final remarks on lunar colours—Quantitative aspects of lunar changes—Concerning lunar intensities—Types of lunar changes—Intensity: variations of lunar marks—Irregular intensity: changes—The moon's atmosphere—Unusual bright spots on the earth-lit moon—Possible lunar meteor—Lunar eclipses—Irregular changes—Concerning the earth-lit moon—The temperature of the moon's surface—Concluding remarks—Bibliography.

THE anxiety of the early telescopists to find analogies between the moon and the earth is still witnessed by the so-called lunar oceans. When better instruments and more careful investigations proved that the two worlds are really very dissimilar, the prevalent opinion of professional astronomers came to be that the moon is a world utterly void of all physical agencies and that no alterations ever occur in its surface features. These views were well summarized by Newcomb:[43*] "A world which has no weather, and on which nothing ever happens—such is the moon."

If such an opinion is completely correct, the moon is indeed a barren field for study; but it is significant that those astronomers who have carefully studied the moon (selenographers) and whose opinion is hence of greatest value in lunar matters have frequently declared that changes do take place and that certain regions no longer resemble earlier maps, descriptions, and drawings. Almost all prominent selenographers have thought that changes do occur on the moon or at least that there exist lunar phenomena not

*Here and elsewhere the superscripts refer to books and papers listed in the bibliography.

explicable by known physical laws. The difficulty in accepting such announced changes as real is that the extent of subjective errors of observation is difficult to ascertain and that the maps, descriptions, and drawings are seldom to be trusted to the degree of accuracy involved by the change; further, the region in question had not usually been observed carefully or frequently before the change was reported. The best evidenced example of a permanent change of this kind was alleged by Schmidt in Linné in 1866. W. H. Pickering reviewed the evidence and concluded, by reasoning which I consider convincing, that a change had actually occurred.[48] Some other possible examples of such changes will be referred to during the course of this paper.

As our colleague Barcroft has pointed out,[2] permanent changes are possible on an atmosphereless moon. The impact of meteorites and the expansion and contraction of the lunar rocks under widely varying temperatures,[71] for example, must certainly exert an effect and perhaps can occasionally produce results observable from the earth. Good photographs of the moon taken over a long period of years may eventually tell us whether changes of this kind do occur.

A more interesting sort of changes, those which repeat themselves periodically each lunation, was discovered by the late William H. Pickering, first in Hansteen in 1891 at Arequipa;[48] subsequently he observed such alterations long and carefully in many places on the moon. We shall later have occasion to mention his work on a number of craters and shall here attempt no necessarily imperfect summary except to note that his results indicated to him the existence of a lunar atmosphere, lunar vegetation, snow, clouds, hoar-frost, etc. Such unconventional views naturally encountered much opposition. The reality of his observations was questioned; but the evidence of photographs, let alone the confirmatory results of completely independent visual work by other observers, has proved that at least his more conspicuous areas behave essentially as he asserted. We cannot speak so confidently of his delicate detail, which he declared is visible only in good seeing and which another observer might draw very differently. McEwen has made some instructive comments on the personal equation in drawings of difficult marks.[40] Granting the

reality of at least the large-scale changes, we next inquire about the soundness of Pickering's interpretation of what he saw. His opponents at first made the absurd suggestion that the dark areas present near lunar noon, which marks he studied, are shadows—a geometrical impossibility.[29] The view at present prevalent is that the variations are entirely due to changes in the angles at which the solar rays are incident upon the lunar surface—an explanation which we shall hereafter call *the incident light theory*. It is to be noted that the moon has been greatly neglected by professional astronomers in recent years[2] and that Pickering's lunar studies were far more extensive than those of his critics.

I first became interested in the matters discussed in this paper when studying under Pickering's guidance at his home in 1935. Since then I have carried on regular lunar observations as vigorously as attendance at college has permitted. I have received valuable assistance in observations, suggestions, and criticisms from a number of astronomers, mostly amateurs. My primary purpose has been to decide whether periodical changes of the kind Pickering studied can be explained by the incident light theory or not. Their not being so explicable would not prove that Pickering's views are correct but would almost certainly indicate that the changes are temperature-effects of some kind, and we shall introduce the term *real changes* to describe alterations due to something else than variations in lighting.

The purpose of this paper is fourfold:

1. To arouse interest in a neglected branch of astronomy.
2. To report on the approximately *7,000* lunar observations made by my colleagues and me between May 1935, and June 1941, and to compare our results with previous work.
3. To call attention to a number of lunar problems and to indicate fields for future research.
4. To suggest plausible explanations of the phenomena studied.

Some Fundamental Ideas

It is very important to know for *any* lunar observation the value of the *sun's selenographic colongitude* (hereafter called simply *colongitude*). This quantity is the longitude of the sunrise termina-

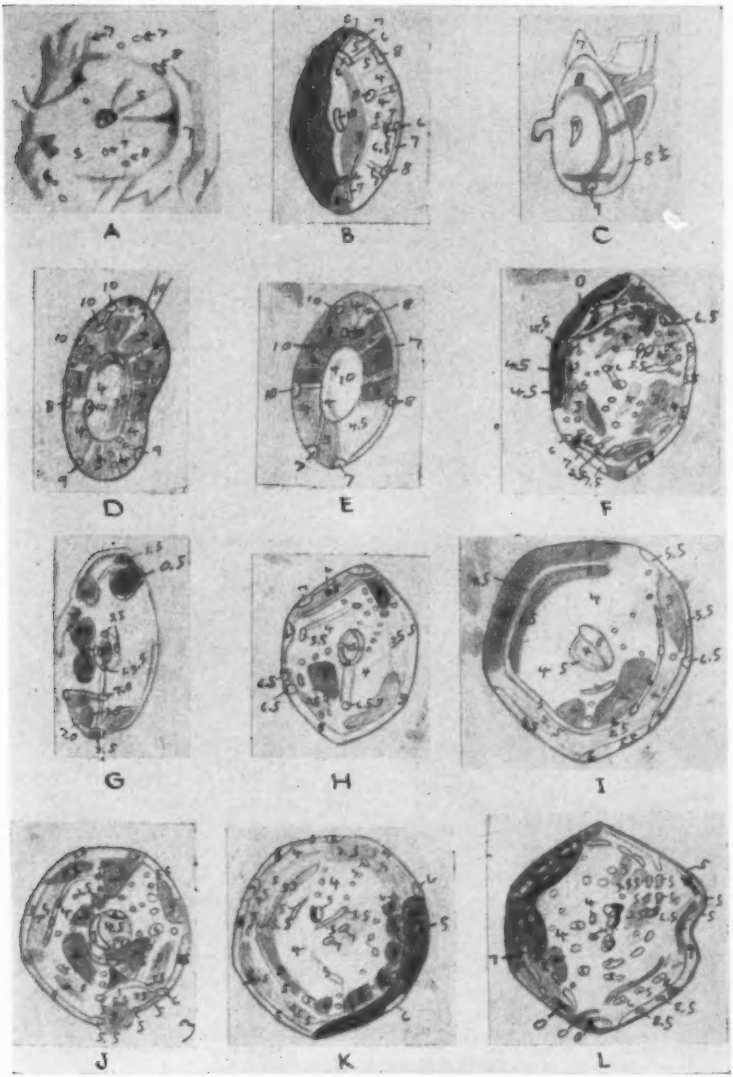
tor measured eastward from the zero meridian and indicates the solar illumination of the lunar region being studied. Colongitude is readily computed with the aid of the *American Ephemeris and Nautical Almanac*, where it is given at 0^h, U.T., for every day in the year; for it increases at a rate of about 0°.5 an hour and 12°.2 a day. This quantity is an approximate measure of phase: new moon comes near colongitude 270°; first quarter, near 0°; full moon, near 90°; and last quarter, close to 180°. We next consider the two causes which prevent colongitude from being an exact measure of illumination (if it were such, then the incident light theory would demand that the appearance of a mark be exactly the same at the same colongitude in different lunations).

The first cause is the moon's libration in longitude and latitude —to be precise, a change not in illumination but in the position of the line of sight with reference to the moon's surface. The resulting variable foreshortening of a circular crater of true diameter 1.000 is readily found by trigonometry and is given in Table I. The first set of rows gives the apparent east-west diameter of such a crater on the equator for average libration, and for the 2 extreme librations, in longitude at different longitudes. The second group of rows shows the apparent north-south diameter of such a crater on the zero meridian of longitude for average libration, and for the 2 extreme librations, in latitude at various latitudes.

TABLE I.—EFFECT OF LIBRATION

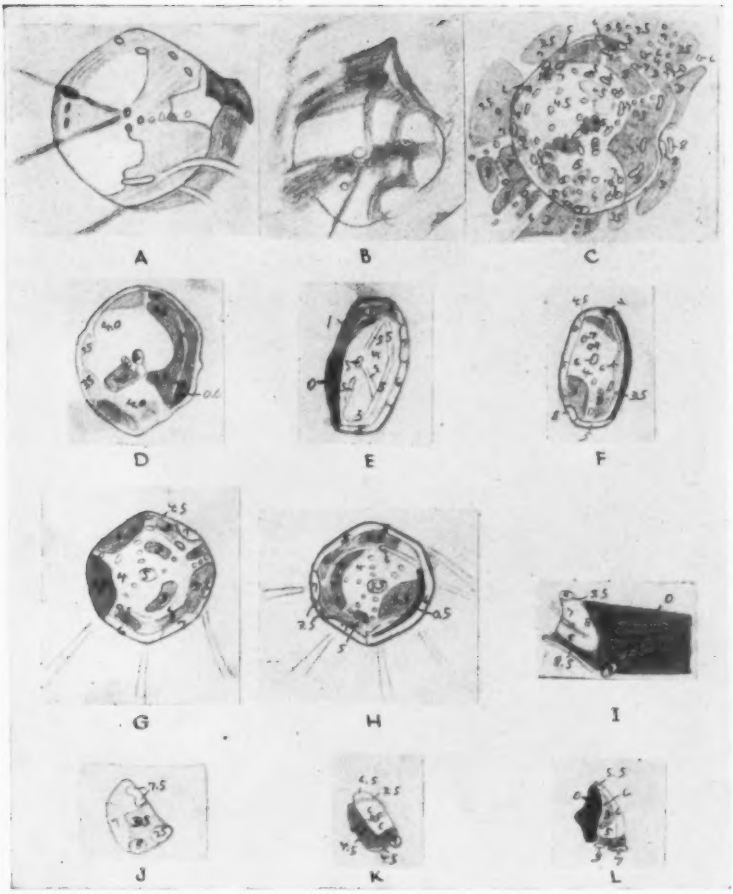
Long.	0°	15°	30°	45°	60°	75°	90°
Average	1.000	.966	.866	.707	.500	.259	.000
One maximum	.991	.992	.926	.796	.612	.387	.135
Other maximum	.991	.922	.791	.605	.379	.126	invisible
Lat.	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**
Average	1.000	.966	.866	.707	.500	.259	.000
One maximum	.993	.990	.919	.786	.599	.371	.118
Other maximum	.993	.929	.801	.619	.395	.144	invisible

The maximum and minimum apparent diameters of craters in other positions may be found accurately enough by interpolating with second differences in Table I. This varying foreshortening



DRAWINGS OF CRATERS

For Key to Figures see back of next Plate.



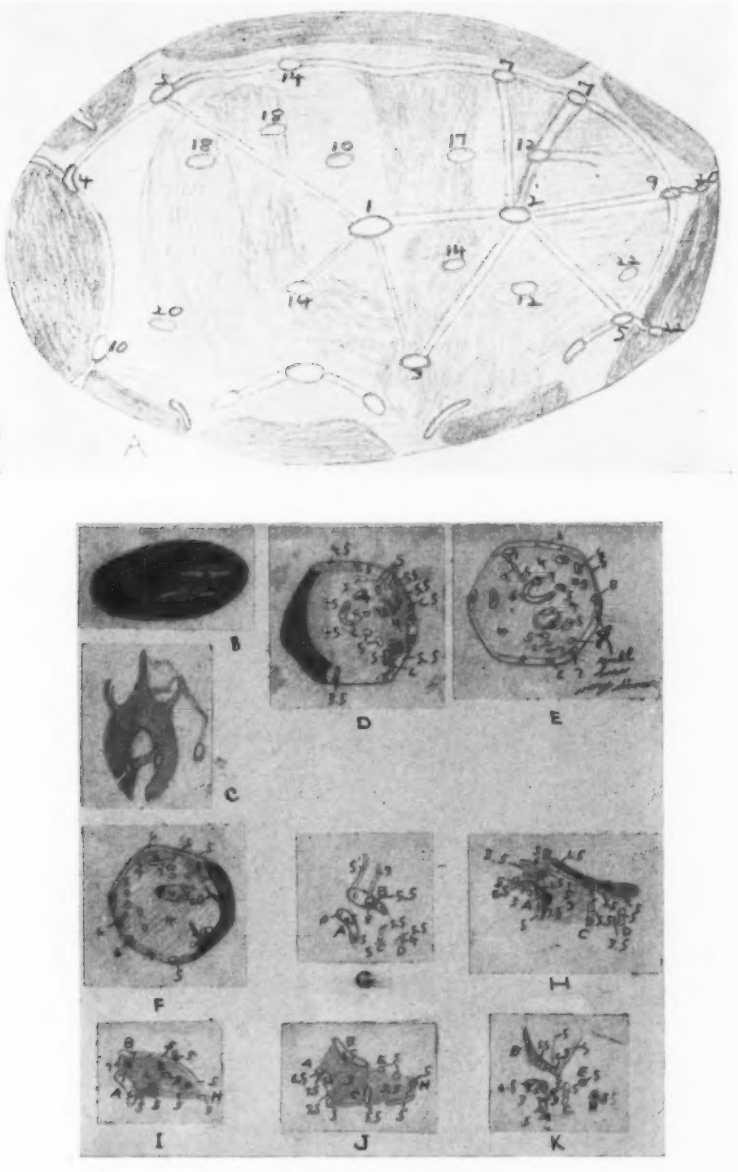
DRAWINGS OF CRATERS

For Key to Figures see back of next Plate.

KEY TO FIGURES ON PLATE ON PREVIOUS PAGE

Fig.	Object	Observer	Date	Time	Telescope	Magn.	Seeing	Tr.	Col.
				h m					°
A	Alphonsus	Cyrus	Nov 10, '40	0 8	10-in. rfl.	120×	4	2	31
B	Aristarchus	Haas	July 31, '36	1 40	10-in. rfr.	228	3	4	57
C	Aristarchus	Barcroft	Aug. 17, '40	8 0	6-in. rfl.	96, 144	6	4	79
D	Aristarchus	Haas	Oct. 4, '36	8 42	10-in. rfr.	228	6	4	134
E	Aristarchus	Haas	Nov. 6, '36	10 15	10-in. rfr.	228	3	4	177
F	Atlas	Haas	May 16, '37	3 28	10-in. rfr.	228	6	3	339
G	Atlas	Johnson	Apr. 10, '38	3 1	5-in. rfl.	177	8	4	29
H	Atlas	Haas	July 24, '37	2 41	10-in. rfr.	158	5	4	102
I	Bullialdus	Haas	Oct. 16, '37	4 12	6-in. rfl.	192	7	3	48
J	Bullialdus	Haas	Oct. 20, '37	4 52	10-in. rfr.	158	5	2–4	97
K	Bullialdus	Haas	July 30, '37	10 9	10-in. rfr.	158	8	3	179
L	Eratosthenes	Haas	Oct. 25, '36	1 35	10-in. rfr.	228	6	3	26

Tr.=Transparency; Col.=Colongitude.



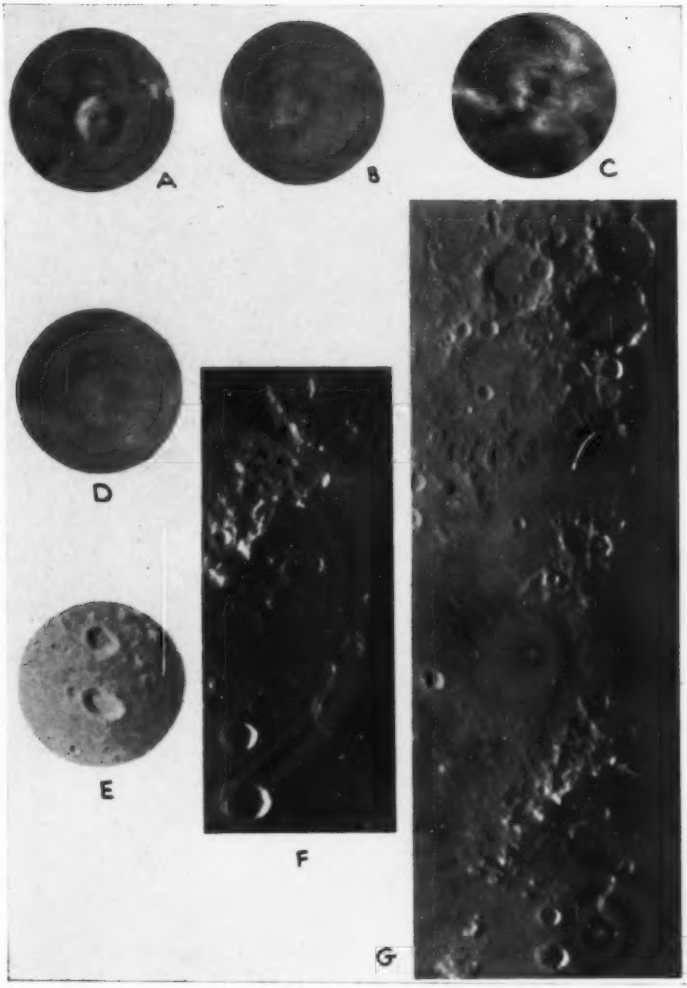
DRAWINGS OF CRATERS

For Key to Figures see back of next Plate.

KEY TO FIGURES ON PLATE ON PREVIOUS PAGE

Fig.	Object	Observer	Date	Time	Telescope	Magn.	Seeing	Tr.	Col.
				h m					°
A	Eratosthenes	Martz	May 4, '36	5 40	10-in. rfl.	110, 290	7	4	64
B	Eratosthenes	Wilson	June 5, '36	5 15	4-in. rfl.	150	7	4	94
C	Eratosthenes	Haas	Oct. 4, '36	7 42	10-in. rfr.	228	6	4	133
D	Eratosthenes	Johnson	Feb. 20, '38	10 35	5-in. rfl.	177	5–7	4	156
E	Kepler	Haas	Oct. 17, '37	1 32	6-in. rfl.	192	5	3	59
F	Kepler	Haas	May 3, '37	9 45	10-in. rfr.	228	5	4	183
G	Manilius	Haas	June 20, '37	1 34	6-in. rfl.	192	8	4	46
H	Manilius	Haas	Sept. 23, '37	6 12	10-in. rfr.	228	5	4	128
I	Pico	Haas	July 6, '38	2 37	10-in. rfr.	228	6	4	11
J	Pico	Johnson	Apr. 13, '38	3 32	5-in. rfl.	177	3–4	4	66
K	Pico	Haas	June 15, '38	9 32	10-in. rfr.	158×	5	4	118
L	Pico	Haas	Aug. 17, '38	9 48	6-in. rfl.	192	7	3	167

Tr. = Transparency; Col. = Colongitude



PHOTOGRAPHS BY WILSON

For Key to Figures see back of next Plate.

(In Fig. A top is N., right is W.)

KEY TO FIGURES ON PLATE ON PREVIOUS PAGE

Fig.	Object	Observer	Date	Time	Telescope	Magn.	Seeing	Tr.	Col.
				h m					°
A	Plato (Map)								
B	Plato	Haas	Sept. 22, '39	1 5	6-in. rfl.	192	5	4	13
C	Riccioli dark area	Johnson	Oct. 28, '39	3 18	8-in. rfl.	213	5	4	93
D	Plinius	Haas	July 26, '36	1 17	10-in. rfr.	228	3	4	356
E	Plinius	Haas	July 2, '36	4 32	10-in. rfr.	228	5	4	64
F	Plinius	Haas	Oct. 4, '36	9 42	10-in. rfr.	158, 228	3	4	134
G	Theophilus peaks	Haas	May 6, '38	1 39	10-in. rfr.	228	5	4	345
H	Theophilus peaks	Haas	July 7, '38	0 28	10-in. rfr.	228	6	3	22
I	Theophilus peaks	Haas	Aug. 9, '38	4 41	10-in. rfr.	158	5	4	68
J	Theophilus peaks	Haas	June 15, '38	9 16	10-in. rfr.	158, 228	5	4	117
K	Theophilus peaks	Haas	Apr. 19, '38	8 33	10-in. rfr.	228	6	4	141

Tr. = Transparency; Col. = Colongitude.

PLATE XV

MOUNT WILSON PHOTOGRAPH H 17
Taken with the 60-inch Reflector, October 15, 1927.

KEY TO FIGURES ON PLATE ON PREVIOUS PAGE

Fig.	Object	Observer	Date	Time	Telescope	Magn	Seeing	Tr.	Col.
				h m					°
A	Eratosthenes	Wilson	June 18, '37	2 5	12-in. rfl.				21
B	Eratosthenes	Wilson	June 20, '37	2 52	12-in. rfl.				46
C	Eratosthenes	Wilson	Apr. 25, '37	5 47	12-in. rfl.				84
D	Eratosthenes	Wilson	June 25, '37	6 46	12-in. rfl.				109
E	Eudoxus shadow	Wilson	Sept. 13, '37	1 15	12-in. rfl.				4
F	M. Huyghens craterlet	Wilson	June 6, '38	1 0	12-in. rfl.				4
G	Ptolemy and vicinity	Wilson	Sept. 13, '37	1 15	12-in. rfl.				4

Tr. = Transparency; Col. = Colongitude.

of detail may be accompanied by considerable *seeming* changes of aspect, especially near the limb of the moon, a matter commented upon by Proctor and Weinek.[71, 79]

The second reason that colongitude is not an exact measure of illumination is that during the course of the year the sun reaches a maximum distance of a degree and a half from the plane of the moon's equator on both the north and south sides; we consequently have slight lunar seasons, the precise analogues of terrestrial ones. For a particular spot on the moon the sun's height will therefore vary slightly at the same colongitude in different lunations because of this changing latitude. (The sun's azimuth also will be affected, but empirical evidence indicates that height is far more important in its effect on lunar changes than is azimuth). This influence will be most marked on craters in high lunar latitudes and near the terminator, as a little thought will show. Table II gives the sun's height for lunar craters at various latitudes on the zero meridian of longitude for colongitudes 2° and 10° with the sun on the equator and at its greatest northern and southern latitudes.

TABLE II.—EFFECT OF SUN'S VARYING LATITUDE

Lat.	0°	15°	30°	45°	60°	75°	90°
Colongitude 2°							
Max. N.	2°.0	2°.3	2°.5	2°.5	2°.3	1°.9	1°.5
Equator	2.0	1.9	1.7	1.4	1.0	0.5	0.0
Max. S.	2.0	1.5	1.0	0.4	−0.3	−0.9	−1.5
Colongitude 10°							
Max. N.	10.0	10.1	9.4	8.1	6.3	4.0	1.5
Equator	10.0	9.7	8.7	7.1	5.0	2.6	0.0
Max. S.	10.0	9.3	7.9	6.0	3.7	1.1	−1.5

In order to measure the illumination of particular places on the moon it is convenient to define the *relative colongitude* of a point P as equal to $l\odot - l_p$, where $l\odot$ is the colongitude at the time in question and l_p is the colongitude when the sun rises upon P. (To prevent l_p from being different in different lunations, we shall further specify that the sun is to be on the equator when it rises.) The relative colongitude is 0° at sunrise (on the average), 90° at noon (sun on meridian of P), and 180° at sunset (on the average).

This quantity is at any moment the same for all craters with the same lunar longitude.

It is of advantage to employ a numerical scale to describe the brightness (intensity) of marks on the moon. Schroeter devised such a scale; his numbers ranged from 0 for shadows to 10 for the brightest marks.[15] The British lunar workers adopted this scale and calibrated it by assigning certain numbers to certain marks;[15] e.g., they called the floor of Endymion 2. Since most, and perhaps all, marks vary in brightness during their lunar days, I question the reliability of such a method of calibration. It is my practice to use 0 for large shadows near the terminator, 4 for *maria* more than 3 days from the terminator, 5 for the host of faint bright spots seen under high illumination, and 10 for a few of the brightest marks; but otherwise I guide myself largely by experience in assigning intensity-numbers.

The symbols λ and β will hereafter be employed to denote lunar longitude and latitude respectively. The former is positive toward the west; the latter, toward the north.

Universal Time will be employed as the basis of dates and times in this paper.

The Observers

There follows a list of those who have contributed lunar observations to us, along with their stations and telescopes and a few pertinent comments. To conserve space, we have omitted the names of some observers who did but very little and that little only under the guidance of one of those listed.

Table III.—The Observers

Observer	*Station*	*Telescope**	*Remarks*
Bachner, Martin	Youngstown, O.	6-in. rl.	
Barcroft, David P.	Madera, Calif.	6-in. rl.	
Beede, T. G.	Youngstown, O.	6-in. rl. (?)	
Beamer, Clifford	Des Moines, Ia.	6-in. rl.	
Brockmeyer, Charles H.	Fredonia, Ky.	2-in. rr.	
" "	"	6-in. rl.	
Buchanan, James D.	Youngstown, O.	6-in. rr.	
Chase, John H.	Youngstown, O.	6-in. rl.	
Cyrus, Charles	Lynchburg, Va.	10-in. rl.	
Frazine, Floyd L.	St. Petersburg, Fla.	10-in. rl.	
Grandmontagne, Leo F.	Youngstown, O.	6-in. rl.	

Observer	*Station*	*Telescope**	*Remarks*
HAAS, WALTER H.	Mandeville, Jamaica	12-in. rl.	W. H. Pickering's Private Observatory
" "	Alliance, O.	10-in. rr.	Mount Union College Observatory
" "	New Waterford, O.	2 6-in. rls.	
" "	East Cleveland, O.	9-in. rr.	Case School Observatory
" "	Des Moines, O.	7-in. rl.	Johnson's telescope
" "	"	8-in. rl.	Johnson's telescope
" "	"	6-in. rl.	
" "	Columbus, O.	12-in. rr.	McMillin Observatory of the Ohio State University
HOUSTON, WALTER	Manhattan, Kans.	6-in. rl.	
JOHNSON, HUGH M.	Des Moines, Ia.	7-in. rl.	Used at 5-in. aperture
" "	"	8-in. rl.	
" "	"	8-in. rr.	Drake Observatory
LANDQUIST, CARL	Madera, Calif.	6-in. rl.	Observed with Barcroft
MARTZ, EDWIN P.	Oak Park, Ill.	6-in. rl.	
" "	Devil's Lake, Wis.	6-in. rl.	
" "	Mandeville, Jamaica	6-in. rl.	Pickering's Private Observatory
" "	" "	3-in. rr.	Pickering's Private Observatory
" "	" "	12-in. rl.	Pickering's Private Observatory
MCLEOD, NOAH W.	Christine, N.Dak.	5-in. rr.	
MILLER, E. A.	Youngstown, O.	6-in. rl.	
PICKERING, WILLIAM H.	Mandeville, Jamaica	12-in. rl.	
ROTH, HARLEY A.	Alliance, O.	10-in. rr.	Observed with Haas
SHANER, RICHARD	Youngstown, O.	6-in. rl.	
SMITH, J. RUSSELL	Smyer, Tex.	8-in. rl.	
VAUGHN, FRANK R.	Des Moines, Ia.	3-in. rl.	
" "	"	8-in. rl.	
" "	"	8-in. rr.	Drake Observatory
WELDY, JAMES W.	Alliance, O.	10-in. rr.	Observed with Haas
WILSON, LATIMER J.	Nashville, Tenn.	4-in. rl.	
" "	"	8-in. rl.	Watkins Institute telescope
" "	"	11-in. rl.	Used for photography

*Abbreviations: rl. for reflector and rr. for refractor.

I made the great majority of the 7,000 observations; the four others who did most are, in order, Barcroft, Johnson, Wilson, and

Martz. The analysis and interpreting of the observational data is mine, and I naturally accept full responsibility for the opinions presented in this paper.

We remark in passing that the rather small instruments our group has employed are large enough to give good results in lunar studies.

Observational Procedure

It will be well to speak next of the manner in which lunar* observations are secured, the more so since information on the proper techniques in observing is not readily available to the amateur. Webb long ago indicated the general precepts by which a beginning observer should guide himself,[78] and we enthusiastically endorse his principle of recording *at the telescope* observing-notes and of making there careful drawings, preferably in a notebook.

In choosing areas to study, one must be guided by one's equipment and experience; a number of interesting regions will be described later. Since it is important to have a record of the appearance of an object under all illuminations, that is, at all times of its lunar day, observers not able to undertake post-midnight work will do well to concentrate on areas in large western longitudes, where the sun sets soon after full moon. To be sure, scattered observations may be very valuable when they can be compared with other results on the same regions. Owing to clouds and other interruptions an observer will usually need several months to secure a fairly complete record of the changes in an area he is studying. The beginner will do well to limit his attention to a few rather small regions, single craters being good objects.

The following data should accompany every observation:

1. The name of the observer.
2. The station of observation.
3. The telescope employed (aperture and whether a reflector or a refractor).

The above items, unlike those remaining, can usually be recorded once for all in a given series of observations.

*Many of the remarks in this section and the next will also apply to planetary observations.

4. The date, including the year.
5. The time, which for lunar work need be recorded only to the nearest minute. Indeed, an error of 5 minutes would seldom be important.

Items 4 and 5 must be accompanied by the kind of time (Central Standard, Universal, etc.) used.

6. The object (or objects) examined.
7. The magnification. The best power to use will depend upon the telescope, the atmospherical conditions at the time of observation, the work being attempted, and the personal tastes of the observer; it is my opinion that powers near 200× are best for most lunar work.
8. The transparency of the atmosphere. Good views of detail are sometimes had through haze, which is common at some stations in certain seasons. I recommend the use of a transparency-scale of 1 (very hazy) to 5 (very clear).
9. The seeing, which measures the steadiness of the atmosphere. The value of undisturbed air in lunar and planetary studies was thoroughly appreciated by Pickering, Douglass, and Lowell; the first-named investigated the meteorological and geographical conditions conducive to good seeing,[55] and the second and third have made some instructive comments on the observational effects involved[9,28] Nights of good seeing are rather infrequent at most stations in the United States and should hence be taken full advantage of. Cyrus, Frazine, Johnson, Smith, Vaughn, Wilson, and I all now use the Standard Seeing Scale of 0 (very bad) to 10 (very good); our results suggest that at most stations in the United States the seeing is usually 4, 5 or 6 on this scale. Incidentally, Pickering found the average seeing at Cambridge for moderate altitudes to be 5[56]. Pickering estimated the seeing by the appearance of the diffraction-rings around bright stars[56]; but such a scheme is not well suited to home-made reflectors, and we "moderns" have guided ourselves by the appearance of lunar detail (sharpness of definition, degree of freedom from vibration, etc.) and by observational experience. Amateurs not finding the Standard Scale adapted to their needs may devise other scales, for adequate word-descriptions make it possible to transform values estimated on one scale into those on another with sufficient accuracy.
10. Any colour-filters or diaphragms used and any additional information of use in evaluating the observation.

Methods of Investigation

Lunar changes have so far been studied in 5 different ways. Drawings (and accompanying word-descriptions) have been the

method most used and are of fundamental importance. Pickering and I have employed previously prepared outlines of craters (and coarse detail) in making drawings; this practice saves time at the telescope and guarantees that all the sketches of a particular object will be on the same scale, but it is true that outlines of craters are affected by libration, especially near the limb, and are often difficult to trace under high illumination. The drawings which will be reproduced later will illustrate "personal equation," which is often disagreeably large in lunar drawings. The use of intensity-numbers on drawings to indicate relative brightnesses and darknesses is to be recommended. That there is plenty of sketchable detail on the moon, much of it still completely unstudied, is shown by the fact that such a crater as Eratosthenes contains more detail than does Mars.[65]

The slight lunar colours have not been much observed. Anyone desiring good results in this field should be guided by the precepts I have discussed elsewhere.[26] Briefly, he ought to use one telescope at a constant magnification, to work only in a sky clear and fully dark, to compare regions studied to assumedly grey *maria* 3 days or more from the terminator, and perhaps to use colour-filters (Eastman Kodak Company Wratten Filters are especially good). The analysis of colour observations should be directed primarily toward discovering changes in colour rather than toward ascertaining the colours themselves, which are too delicate to be described objectively.

Some years ago I suggested the study of intensities as a separate attack on the problem of lunar changes.[23] Estimates of intensity are best made only in a clear and dark sky and preferably in good seeing also. All lunar changes (except those in colour) may be interpreted as intensity-changes in the areas involved.

A quantitative approach is that of general lunar surveys; one here studies the entire moon instead of a few selected small regions, and tries to note the prevalence and conspicuousness of the various kinds of changes.

To these four visual methods we must add photography. It is true that a skilled observer, by taking advantage of moments of

relatively good seeing, can see more than is shown on most photographs; but photography has the advantages of being free from subjective errors, of providing a permanent record that may be studied at any future date, and of distinguishing slight contrasts not readily perceptible to an eye dazzled by the brilliant moon. The excellent Mount Wilson lunar photographs deserve mention; Goodacre found that their finest detail taxed the power of his splendid 10-inch refractor.[15] The best photographic atlas of the moon for the student of lunar changes is Pickering's;[53, 54] the photographs do not equal in quality the Mount Wilson ones, but this atlas has the excellent feature of showing each section of the moon under 5 different illuminations: sunrise, morning, noon, evening, and sunset. Most other lunar photographs are sunrise or sunset views and hence reveal nothing of the interesting detail present in some regions near noon. A systematic and carefully planned programme of photography at a large observatory would shed much light on lunar problems. Let us hope that the more than 400 excellent photographs taken at Mount Wilson in 1938[82] will soon become available to those interested in lunar matters. The image of the moon is rather small for photographing with small telescopes, but Wilson has obtained good results and at my request has kindly written the following article (which I have edited and condensed to a small extent):

The moon is a good subject for experiments in amateur astronomical photography. Fair results can be attained with small telescopes, and even a long-focus camera will suffice to illustrate phenomena of occultations and eclipses. To record details of the surface, however, it is best to use a telescope which furnishes as large an image as possible, for small apertures will lack the resolving power needed to show fine detail.

In a telescope of 96 inches focal length, the image of the moon at the principal focus is about 7/8 of an inch in diameter. With fine-grain films this small image, if sharp enough, can be enlarged sufficiently to disclose rather small detail. For example, when the Triesnecker clefts are favourably illuminated they can be recorded with an aperture of slightly less than 12 inches. But since detail may be beyond the resolving power of the photographic emulsion, it is best to magnify the focal image in the telescope in order to secure a larger image on the film.

There are two methods of enlarging the focal image: one is to insert a double-concave lens in the path of the rays between the flat mirror or diagonal prism

and the film; the other is to employ a positive lens, a compound eyepiece corrected for chromatic and spherical aberrations. The writer has used satisfactorily an orthoscopic eyepiece and an achromatic doublet arranged in the form of a rectilinear lens which magnified up to 8 or 9 times, the lens working at F/4. Negatives obtained in good seeing can be further enlarged to gain finer detail. The writer has succeeded in photographing lunar marks having a diameter of only about three-quarters of a mile; the resolving power of his 12-inch telescope is 0".43 or about 0.47 miles on the moon's surface.

Exposures for lunar photographs can be made so short that mechanical driving is not necessary, though a good drive is recommended. A telescope of relative aperture F/8 has the speed of a camera lens of the same relative aperture. On fast films exposures of 1/25 of a second are possible. For an enlarged image longer exposures are needed. For the half moon and an enlargement of 5 diameters, with Eastman Super XX film or agfa Superpan Press exposures of 1/6 to 1/10 of a second supply images sufficiently dense. In making images of this or lesser magnification of the full moon it is preferable to employ slower films in order to gain contrast. Tricolour filters and infra-red film used with a red filter necessitate either smaller magnifications or exposures longer than 1/8 of a second.

Drawings and Descriptions

We now discuss alphabetically by regions (chiefly craters) the results secured by drawings and descriptions. A few rarely observed objects showing nothing not studied elsewhere are not considered. We supplement our remarks with photographs of copies of 34 drawings, which show views typical of many more drawings; in these photographs lunar south is at the top, and lunar east is at the right. In the data accompanying the photographs we use the seeing scale of 0 to 10 and the transparency scale of 1 to 5, both of which were mentioned before. There is given for each region its lunar co-ordinates, the colongitudes of sunrise, noon, and sunset, and the number of observations and drawings secured (the former include the latter).

1. *Alphonsus.* $\lambda -3°$, $\beta -13°$. Sunrise at colongitude 3°, noon at colongitude 93°, sunset at colongitude 183°. 12 observations. 8 drawings.

Near full moon the position of Alphonsus is marked by several strikingly black spots, which Pickering studied.[48] He found that the spots are darkest near noon, behaviour he attributed to vegetation; and he discerned in the centre of each spot a minute craterlet. Cyrus has made observations agreeing well with

Pickering's and confirming that the spots are darkest near noon; we reproduce in Figure A on Plate XI a sketch by the former. The interior craterlets are well shown on Mount Wilson Photograph H 7, which was recently reproduced[19]; the spots themselves are also exhibited to advantage on Mount Wilson Photographs H 17 (Plate XV) and 322 and are apparently actually then darker under higher illumination.

Some detail is unavoidably lost is reproducing photographs, and Plate XV may not show some things mentioned in the text which are readily seen on a Mount Wilson photograph H17 that I have at hand.

2. *Alpine Valley Dark Area.* $\lambda+4°$, $\beta+48°$. Sunrise at colongitude 356°, noon at colongitude 86°, sunset at colongitude 176°. 5 observations. 1 drawing.

At colongitude 12° on November 1, 1938, a Public Night at the Case Observatory, Dr. J. J. Nassau called to my attention a very dark area, comparable to shadow, in the mountainous region south of the Valley of the Alps. I subsequently estimated the intensity of this area to be 1.5 at 22°, 3.0 at 36°, and 3.5 at 46° and at 71°. Such progressive fading is common on the moon, and this mark is a good example. Mount Wilson photographs show that this dark area is not visible at sunset.

3. *Anaxagoras.* $\lambda-8°$, $\beta+72°$. Sunrise at 8°, noon at 98°, sunset at 188°. 11 observations. 9 drawings.

This crater shows a brilliant east rim at sunrise, a brilliant west rim at sunset, some bright floor spots, and several vertical streaks on the walls—all common appearances. On July 10, 1935, at $4^h\,5^m$, colongitude 20°, I suspected tops of hills in the shadow under the southwest rim.

4. *Aristarchus.* $\lambda-47°$, $\beta+24°$. Sunrise at 47°, noon at 137°, sunset at 227°. 154 observations. 112 drawings.

Figures B–E on Plate XI show the progressive changes occurring in this crater each lunation. Of special interest are the dark bands on the brilliant east inner wall. These bands were apparently first noticed by Goodacre and Krieger[18] and are well shown on Mount Wilson Photographs H 12, H 17 (Plate XV), 322, and 363. Probably the most systematic study of them so far is one I carried on in 1935-6; my published report[24] needs a few corrrections.

The "long, curving very bright band" on the east inner wall is really merely the southeast rim of Aristarchus. Near 75° the land outside the rim assumes a "banded" appearance similar to that of the inner wall. By 85° the rim *seems* to be a curved bright band between dark bands on each side, and the true shape of Aristarchus is not easily recognized. The rim subsequently becomes duller and never looks like a "band" after 145°, for at that time the "expanded" outlines yield place to the true walls.

The "bright spot . . . at the foot of the northwest wall" is actually only the central peak, which is apparently shifted in position by the "spreading" of the

walls. This peak is really very bright from sunrise to sunset, but no definite cycle of intensity-variations has been determined.

Barcroft has published some of his results on Aristarchus in 1939-40.[1, 2] He confirms, as does Johnson, the progressive darkening of the bands and has, moreover, twice noted near 74° a peak on the west rim. A remark that "the outside shadow of the west wall reveals many peaks and irregularities on the west rim," which I recorded at 225°, favours the existence of such a peak.

The dark bands probably widen somewhat during the course of their lunar day. To me they always look much wider than the bright bands separating them from each other, but Barcroft and Martz make the bright bands wider than the dark ones.

On September 17, 1937, at $2^h\,30^m$, colongitude 53°, Johnson noted some unusual appearances. Only the east inner wall was illuminated. Along its foot, and thus bounding the interior shadow, he saw a bright streak, which is recorded on no other drawing near the same colongitude. Johnson later looked for this streak unsuccessfully. He also saw at the foot of the wall (and later did confirm) 2 tiny crater-pits full of shadow much blacker than the large internal shadow. Johnson plausibly suggests that sunlight is reflected from the brilliant east inner wall into the large shadow and so lightens it.

Schroeter, Smyth, and Elger, among others, have asserted that the brightness of Aristarchus by earthshine varies greatly,[78] a matter meriting careful investigation. At 0^h on December 2, 1940, Vaughn distinguished Aristarchus in the dark hemisphere as a bright spot; and Barcroft perceived this crater by earthshine on March 31, 1941, at $3^h\,15^m$ although he did not see distinctly the outlines of the *maria*. Perhaps Aristarchus was unusually brilliant on those two occasions.

5. *Aristillus Dark Bands.* $\lambda+1°$, $\beta+34°$. Sunrise 359°, noon 89°, sunset 179°. 21 observations. 4 drawings.

On the northwest inner wall of Aristillus is a dark band which extends beyond the rim, where it widens. Pickering observed the behaviour of this band and of other marks in the vicinity;[57, 58] he found that the band really consists of 2 close streaks ("canals"), which are more easily split outside the rim than on the inner wall. He suggests the resolving of the inner "canals" as a test of definition; he asserted that excellent seeing, at least an 8-inch aperture, and a magnification of 300× or more are necessary for success and that the "canals" are most easily split in the intervals 35°-65° and 110°-140°.[60]

The inner "canals" were divided by Slipher,[76] Jarry-Desloges,[61] and Maggini;[38] the last-named made a careful study of Aristillus and confirmed many of Pickering's results.[38] Aitken at Lick could not resolve the inner bands,[60, 61] but they were easily split with the Mount Wilson 100-inch.[38]

Barcroft and Martz have each been partly successful in splitting the outer bands. On successive nights in November, 1939, the former found the bands to be darkening steadily, a result in accord with Maggini's report that maximum darkness comes at 70°.[38] On April 22, 1940, at 87° in seeing 6–7 I could not

divide the bands with the O.S.U. 12-inch refractor. Johnson was three times unsuccessful with his 8-inch reflector but on June 5, 1941, at 33° in seeing 7–8 with the Drake 8-inch refractor found the outer pair easy to separate and the inner ones barely resolvable, an appearance simultaneously confirmed by Vaughn. Johnson has seen several ridges or terraces interrupting the course of the inner "canals."

6. *Arzachel.* $\lambda-2°$, $\beta-18°$. Sunrise 2°, noon 92°, sunset 182°. 3 observations. 1 drawing.

At 6°–7° on January 6, 1941, and again at 3°.0–5°.5 on March 6, 1941, Barcroft found that the sunrise shadow of the central mountain was far blacker than that of the west wall. Mount Wilson Photographs H 6 and H 7[19] indicate that the central mountain does not cast an abnormal shadow near sunset.

7. *Atlas.* $\lambda+44°$, $\beta+47°$. Sunrise 316°, noon 46°, sunset 136°. 58 observations. 51 drawings.

Johnson and I have devoted much time to this crater, and several of the others have made confirmatory observations. The general cycle of changes is shown by Figures F-H on Plate XI and can also be followed on nine plates (3, A-E and 5, A-D) in Pickering's Photographic Atlas.[53, 54]

The most interesting marks on the floor are 2 dark areas, one near the south wall and the second in the northwest portion of Atlas. Elger and A. S. Williams discovered that these spots are variable in darkness.[15] Pickering spent much time on them and found that they, like their cousins in Alphonsus, grow darker as noon approaches but lighten and become smaller in the evening and contain tiny craterlets.[48] I have found the southern area to be about 1 in intensity and the north-western area to be about 2 during most of the lunation; probably both of them are lighter than the figures above under a low sun, but the effect is augmented by the fact that the whole floor is then darker than near noon. Johnson in August 1937, observed that the southern spot darkened from colongitude 358° to 48° and then became smaller and lighter after 85°. These 2 dark areas behave differently in different lunations in the late afternoon, as is shcwn by the following table of observations in the interval 105°–129°. The only progressive change well supported by the table is a decrease in size. Some of the varying results are due to differences in telescopes and in atmospheric conditions, but other deviations are too large to be plausibly ascribed to errors. We correlate results with the sun's altitude h rather than with colongitudes.

TABLE IV.—ATLAS DARK AREAS, 105°–129°

Date	*Observer*	h	*Observation*
July 3, 1939	HAAS	19°.1	S spot 1.0, NW spot 2.0
Sept. 18, 1940	"	18.9	S spot 0.5 and NW spot 1.5; at least the latter getting smaller

TABLE IV—(*Continued*)

Date	*Observer*	*h*	*Observation*
June 25, 1937	"	18.1	Both spots 2.5
July 21, 1940	"	17.9	S spot 1.0, NW spot 2.0
Nov. 28, 1939	"	17.9	S spot 1.5, NW spot 2.0
Aug. 22, 1937	JOHNSON	16.8	S spot lightened
Aug. 20, 1940	HAAS	14.9	S spot 1.0 and NW spot 1.5; both reduced in size
June 22, 1940	"	14.2	S spot 0.5, NW spot 1.5
Mar. 26, 1940	"	12.7	S spot 1.0, NW spot 2.5
July 25, 1937	"	12.5	Both spots 1.0
June 15, 1938	"	12.5	Both spots 1.3
Aug. 13, 1938	"	12.4	S spot 4.4, NW spot 1.0
Sept. 19, 1940	"	10.8	S spot 1.0 and NW spot 2.5; both altered in shape
Sept. 19, 1940	BARCROFT	10.6	Dark spots gone*
Apr. 28, 1937	HAAS	10.6	S spot 2.5 and NW spot 3.0; both much changed in size and shape
July 22, 1940	"	9.8	Both spots 2.0 and much reduced in size
May 17, 1938	"	9.5	Both spots 1.6
Aug. 23, 1937	JOHNSON	8.5	S spot lightened
July 15, 1938	HAAS	7.8	S spot 4.9, NW spot 1.6
June 5, 1939	"	7.6	S spot 1.5, NW spot 2.0
Apr. 25, 1940	CYRUS	7.5	Spots very dark
Aug. 3, 1939	HAAS	6.9	Both spots 1.5
Oct. 19, 1940	BARCROFT	6.7	Dark spots very small
Sept. 12, 1938	JOHNSON	6.1	Both spots 3.0
Apr. 18, 1938	HAAS	5.8	Both spots 1.3
Sept. 23, 1937	"	5.2	S spot 0.5, NW spot 2.0
Aug. 21, 1940	"	5.0	Dark areas gone; floor 2.5 to 3.0 in their positions
Aug. 14, 1938	"	4.3	S spot 0.5, NW spot 1.0

*Evidence of a marked decrease in size.

Johnson made a surprising observation on February 14, 1938, at 2^h55^m, colongitude 79°. He remarked that the southwest rim was very dark, almost equal to shadow; neither he nor I have seen any similar appearance near this colongitude in any other lunation. No true shadow can possibly exist on the *west* rim of a crater at relative colongitude 123°, almost 3 days past noon.

The east and northeast rims and some ridges near the feet of the corresponding inner walls are bright at sunrise but are no longer conspicuous at 0° and darken near 110°, just before being covered by shadow. Conversely, the south and southwest rims are still shadowed at 5°, attain intensity 5 as late as 30°, and finally reach 9 or 10 by sunset. Likewise, the west rim is dull almost all the time

Atlas is illuminated but brightens suddenly in the last few days of this period to reach 10 at sunset. Such low-sun brightenings are very common on the moon.

A number of dark areas on the floor near the southwest, north, and east walls emerge from shadow very dark and subsequently lighten—behaviour not uncommon.

It will be noticed on Plate XI that Johnson's bright streaks coincide with my rows of small bright spots. I think the latter aspect the more probable, for in my early lunar work I saw similar bright streaks which I later resolved into their component spots. Only one of these small Atlas spots, which are presumably either hills or craterlets, is of individual interest; it lies roughly midway between the north end of the central mountain-mass and the north rim. This spot is inconspicuous up to 350°, then brightens rapidly to reach intensity 7 by 20°, fades after 95°, and is dim again at sunset. Johnson once at 126° saw the spot to be very dark, about 1, as I also once did at 321°.

From about 340° to about 120° the central mountain-mass appears to consist of a dark centre with a bright edge, on which are several bright spots. On one date at 332° I noted that the bright spot on the north end is a crater.

When the ridges near the foot of the west inner wall first come into sunlight they brighten very rapidly, and I have twice detected appreciable changes in 2 hours or less near 339°. Incidentally, these ridges, and probably also those at the foot of the southwest inner wall, are brightest at sunset.

8. Beer and Beer A. $\lambda -9°$, $\beta +27°$. Sunrise 9°, noon 99°, sunset 189°. 28 observations. 2 drawings.

I have frequently noticed that the craters Beer resemble the twin craterlets Messier and Pickering, which go through striking apparent changes in size and shape;[43, 53, 54] and I accordingly asked Barcroft to investigate whether the craters Beer are subject to similar variations. Barcroft regularly found the pair identical but between 70° and 120° described them as "just spots," evidence that he felt uncertain whether he were viewing the true walls or not. He noted small dark specks in their centres under that lighting.

9. Bullialdus. $\lambda -22°$, $\beta -21°$. Sunrise 22°, noon 112°, sunset 202°. 30 observations. 25 drawings.

The general cycle of changes is indicated by Figures I-K on Plate XI.

Goodacre found a "fine composite central peak, very bright at full";[15] I usually saw this object as a dull mass with bright edges (Figure J). Parts of it are 7 and 8 in intensity from 45° to 165°; but it is rather dark under a low sun, some portions being 1 when last struck by the solar rays. The sizable sunset shadow of this mountain shows that its west edge is raised well above the floor. The appearance of the mass between 170° and 197° may be different in different lunations.

On the floor under high lighting are a large number of tiny bright spots. Of greater interest is a ridge, which almost encircles the crater, at the foot of the inner walls. The east parts of this ridge are bright at sunrise, gradually grow dimmer, and darken before being engulfed in the sunset shadow; the last aspect

is shown on Mount Wilson Photograph 363. Similarly, the west parts emerge dull from the sunrise shadow.

The east rim of Bullialdus is intensity 8 at sunrise, dims steadily all day, and finally darkens just before the sunset shadow enters the crater; conversely, the west rim is dark just after the sunrise shadow leaves, brightens all day, and is 6 to 7 at sunset. (The bright spot drawn on the east rim in Figure K is really on the *outer* wall). The north and south rims lack such definite intensity-trends and are never as bright as the east and west rims at their maxima. Dark areas on the corresponding inner walls behave similarly; those on the east inner wall become very dark before being shadowed, and those on the west inner wall emerge very dark from shadow.

Under low illumination the floor is dark (once called 1 at 29°) and uniformly shaded; under high illumination it is light and contains several dark areas. The large one northeast of the central mountain (Figure I on Plate XI) comes into being by lightening less rapidly than adjacent portions of the floor; it then, between 45° and 65°, *apparently* expands in a clockwise direction to give rise to dark areas in the northwest and west parts of the floor (Figure J). There develops simultaneously a dark area between the central mountain and the south wall. All dark areas lighten after 145°, and by 175° not one can be seen.

On several drawings near 180° the floor is shown darkened just east of the ridge at the foot of the west inner wall (Figure K). Referring to Goodacre's remark that "the interior is obviously convex,"[15] we can plausibly attribute this appearance to the sinking sun's inability to illuminate properly the extreme opposite edge (sunset in lunar east) of a convex floor.

10. Cauchy. $\lambda+38°, \beta+10°$. Sunrise 322°, noon 52°, sunset 142°. 9 observations.

Barcroft reports that under low illumination this crater is seen to be deep and round but that under a high sun it resembles a mountain (e.g., Pico). At 350° the crateriform nature is still unmistakable; at 15° the east wall is brightening, the west wall is dim, and there is a dark speck in the centre; from 40° until at least 90° Cauchy *seems* to be a peak, and Barcroft thinks that probably only the east wall is then seen. The aspects of this crater on Plates 3, A-E of Pickering's Photographic Atlas[53, 54] are compatible with such a cycle of changes; however, the reported late forenoon brightening of the east wall is surprising (recall the *typical* behaviour of the east walls of Atlas and Bullialdus).

11. Conon-Bradley Region. $\lambda+2°, \beta+22°$. Sunrise 358°, noon 88°, sunset 178°. 9 observations. 5 drawings.

The large-scale changes in this region are shown on Plates 7, A-E and 9, A-E in the Atlas.[52, 54] Pickering here found varying bright spots, the alterations of which he ascribed to clouds and to patches of snow, and high-sun dark areas, the presence of which he attributed to vegetation.[64] I think that he was partly misled by ordinary low-sun brightenings, which are too common to represent *real changes* (as previously defined).

Martz has confirmed the forenoon fading of some of Pickering's "snow

fields"; and a drawing he made on May 4, 1936, at 64° agrees very well with the one by Pickering at 70° which is reproduced as Figure 14 of the latter's paper.[64] The east rim of Conon is at first brilliant, Vaughn calling it 8 at 22°, but is dimmer by 76°. On February 6, 1941, at 22° Vaughn drew on the floor of Conon a mark of which he said: "The patch of intensity 5.0 was quite vague, and not too definite in its outline." Such a description strongly suggests that Vaughn's "patch" is Pickering's floor "cloud"; if so, it developed abnormally early in the lunation in question.[64] In May 1936 Martz saw nothing of this "cloud" at 28°. Martz and I agree that a shadow in the Apennines east of Conon is darker than neighbouring shadows from 27° to 35°; I once found it to be still "normal" at 23°.

12. Eratosthenes. $\lambda -11°$, $\beta +14°$. Sunrise 11°, noon 101°, sunset 191°. 114 observations. 90 drawings.

The cycle of changes occurring in this crater is illustrated by Figure L on Plate XI and Figures A-D on Plate XII. The late afternoon changes are shown well on Mount Wilson Photographs H 12, H 17 (Plate XV), 322, H 5, H 8, H 9, and 363. The coarser changes may be followed on Plates 9, A-E and 11, A-E in the Photographic Atlas[53, 54] and on Figures A-D on Plate XIV, photographs by Wilson.

Near sunrise the floor of Eratosthenes is almost uniformly shaded, but soon darker portions become faintly visible (Figure L on Plate XI). These areas are prominent near noon and then conceal the outlines of the crater (Figures A and B on Plate XII). Toward evening some of them fade out, but others darken until they are indistinguishable from shadow (Figures C-D).

Pickering considered these dark areas, in which he saw "canals" and "lakes" similar to those on Mars, to be vegetation.[64] He supplemented his visual work with a well-spaced lunation-long sequence of photographs.[65] He later published a set of drawings made with a 3-inch finder;[63] these show about all that can be seen in the United States by amateurs with ordinary telescopes under average conditions. He reported in some detail the changes in size and shape of the dark regions and gave examples of varying behaviour in different lunations.[65] He conducted a micrometric study of the shifts in position of a dark band he named *Main*; of it he said:[66] "this run advances up hill in a direction inclined at an angle of about 45° *toward* the setting sun. . . . It moves transversely through something over its own breadth, leaving a white area behind it. It moves at a different speed in different portions of the same lunation, and moreover at different speed during the same portion of different lunations. It seems to follow no definite law. . . . [Its motions] are most readily and rapidly indicated by the constant changes occurring in its position angle, or direction, with regard to two bright craterlets in its immediate vicinity. Other runs [long narrow markings] in its neighbourhood do not change." In subsequent papers[67, 68, 69] Pickering discussed a maze of delicate "canals" and "lakes" near the south rim and reported micrometric measures of the shifts of some of these marks across the surface. He found another "run" that moves differently in different lunations.[63] He further

reported that the rim of a shallow crater east of the central peaks is occasionally brilliant near 20°.[88] His results have been well confirmed by Maggini[68] and Hamilton.[39]

To report the results of our group's study of the changing dark areas we shall describe the behaviour of six of them.

A region a little east of the central peaks is like the rest of the floor when it first receives sunlight. By 25° the east half of the crater is darker than the west half. When the mark in question is first individually recognizable near 40° its intensity is above 3. It darkens steadily, is pronounced by 65°, and is perhaps the darkest mark in Eratosthenes at 90°. This mark is lighter at 135°, when it has become part of a very large triangular dark area based on the east wall (Figure C on Plate XII). This whole region has darkened to 1 by 155° and is soon afterwards equal to shadow.

A dark area south of the central peaks is visible by 25° and perhaps sooner. It remains about 3 until 75° but subsequently lightens and is gone by 135°.

Our third dark area, just northwest of the central peaks, is not definitely formed until about 45°, although Martz once drew it at 27°. This mark grows steadily darker and by 110° is perhaps the most conspicuous dark area in the crater. It remains unchanged while its fellows fade and is hence at 163° even more outstanding (Figure D). It then suddenly fades out, and by 177° there is no trace of it.

A dark area on the south wall is faintly present at 20° (probably even earlier). By 60° this mark is part of a large area extending both outside the rim and down on to the floor (Figure B). Not changing much until after 135°, this area then imitates the late afternoon darkening of the large triangular region already mentioned but is still lighter than shadow at 182°.

A dark area on the north-northwest inner wall emerges from shadow in 2′ intensity at 26°. By 60° it has lightened to 3 and lies partly on the inner wall and partly outside the rim. Whether it has advanced outward to produce this appearance is uncertain. It continues to lighten and reaches complete invisibility near 160°.

Our final dark area, just outside the northeast rim, near 25° emerges very dark from the outer sunrise shadow of the east wall. At 45° it is much lighter. At 60° it covers part of the inner wall, but whether or not it actually has advanced down the interior slope is still undetermined. The inner wall is no longer darkened at 140°; and the outer area, which has been progressively fading, also disappears near that time.

On December 5, 1935, colongitude 23° to 25°, Martz thought that he detected in the period of 4 hours great changes in position among the bright areas near the east wall, behaviour suggesting shifting lunar clouds to him at the time. Several other observations near the intervals 23°–25° and one in it by Johnson show nothing similar; moreover, Martz himself later expressed misgivings about his results in personal conversation with me. It nevertheless appeared desirable to mention a matter of such great interest.

I saw many small bright spots on the floor (Figures L on Plate XI and C on Plate XII), some of which Martz detected (Figure A on Plate XII); but Johnson drew bright bands in their positions. Incidentally, certain bright spots depicted by Maggini[66] were overlooked by Pickering.[65] Most of these bright spots reach their maximum intensity near noon, but two of them close to the north-northeast wall (Figure C on Plate XII) appear to be brightest 3 days after noon.

As usual, bright spots on, or at the foot of, the east inner wall are brightest at sunrise; such marks oppositely placed are brightest at sunset. A bright spot (or probably two spots) on the *east outer wall* (Figure C) emulates marks on the similarly slanted *west inner wall* by brightening as sunset approaches.

The three principal central peaks under a low sun are seen to be distinct from each other and then cast shadows which are readily visible (Figures L on Plate XI and D on Plate XII). Under a high sun they are much brighter, with maximum light near 130°, but are difficult to identify in the maze of detail then covering the floor.

The early morning darkness of the extreme east edge of the floor (Figure L on Plate XI) presumably shows that the floor is convex by means of reasoning previously employed.

13. Eudoxus Shadow. $\lambda+16°$, $\beta+44°$. Sunrise 344°, noon 74°, sunset 164°. 29 observations.

The sunrise shadow in Eudoxus is distinctly darker than the one in Aristotle from 356° to 15°. I have seen this appearance in nine different lunations; and two astronomically inexperienced, and hence entirely unbiassed, former Mount Union students have confirmed it. It is also shown by photographs: on Plate 5A of the Atlas[53, 54] at 358°; on a published photograph[17] taken at the Griffith Observatory by Martz on July 16, 1937, at about 6°; on a photograph taken by Wilson on September 13, 1937, at 4°, Figure E on Plate XIV; and on one by Barcroft on May 15, 1940, at 8°.

The evening shadows of the two craters are equal in darkness.

14. Kepler. $\lambda-38°$, $\beta+8°$. Sunrise 38°, noon 128°, sunset 218°. 27 observations. 26 drawings.

We exhibit a morning and an evening view (Figures E and F on Plate XII); near noon Kepler shows the same kind of detail as Bullialdus does under a high light. Mount Wilson Photographs H 12, H 17 (Plate XV), 322, H 9, and 363 show part of the cycle of changes in the former crater.

There are two dark areas on the floor of Kepler, one in the north and the other in the south (Figure F). Neither is present when sunlight first strikes the floor, but both are recognizable by 65° and marked by 80°. They then preserve their shapes and an intensity of about 3 until 185°. By 200° they have darkened to 1 and soon afterwards are immersed in shadow. There also lie on the floor some bright spots and streaks and a central mountain, so described by Goodacre[15] but *apparently* shown as a craterlet on Mount Wilson Photograph H 9.

At sunrise a ridge at the foot of the east wall is brightened, and the east rim is then brilliant. Most conspicuous of all is a spot on the southeast wall

(Figure E); the outer morning shadow of the east wall suggests that this spot lies on a peak. These eastern bright areas fade gradually as the lunation advances. At 190° the east rim becomes very dark preceding the entrance of shadow into the crater, and the eastern half of the floor at that time is extremely dark. The same kind of changes, but always in the opposite phase, occur near the west wall. Sunset brightenings are well exemplified by a bright area on the northwest inner wall (Figure F), which attains intensity 10 as the sun sets on Kepler; the outer sunset shadow of the west wall reveals that this mark is on, or near, a peak.

There may be present on the walls under a high sun a number of vague dark bands. These are perhaps most conspicuous near noon but are too light to be studied well.

15. Lichtenberg. $\lambda -67°$, $\beta +32°$. Sunrise 67°, noon 157°, sunset 247°. 5 observations.

Barcroft has noted a large dark area west of Lichtenberg; this mark is forming at 87°, is strikingly dark at 115°, and is much lighter by 163°. Mount Wilson Photographs H 17 (Plate XV), 322, and 363 and Plates 13, B-E and 15, A-D in the Atlas[53, 54] all show this dark area; but the colongitudes are such that no check on Barcroft's results is possible.

16. Linné. $\lambda +12°$, $\beta +28°$. Sunrise 348°, noon 78°, sunset 168°. 63 observations.

In summarizing work on Linné up to 1898 Pickering concluded that:[48] (1) A crater about 10 kilometres (6 miles) in diameter disappeared between 1843 and 1866. (2) A very shallow crater about 4".5 in diameter seen by at least ten different observers in 1867-8 had become entirely invisible by 1897. (3) In 1866-8 there appeared on the summit of a hill, which is well shown in a drawing by Corder[13], near the vanished crater a minute deep craterlet that increased its diameter from 0".2 to 1".8 in rather more than a year, but it had shrunk to 0".8 by 1897. (4) Photographic evidence indicates that the white spot surrounding Linné decreased steadily in size and brightness from 1851 to 1894.

On June 5, 1941, at 33° Johnson and Vaughn, using the Drake 8-inch refractor at 480× in good seeing, noted: "Linné is seen to be a large diffuse bright area in the centre of which is a minute 'circular black spot,' brightened, perhaps, at the edge as if rimmed. . . . It appears to be a deep shadowed pit." The "pit" must be very deep, for the sun's elevation above Linné at the time was fully 38 degrees. Johnson and Vaughn may well have been viewing the "minute deep craterlet"; if so, this object must now be less than a second in diameter, for I have never even suspected it.

Equally interesting are the changes Pickering discovered in the size of the white area itself[48] and demonstrated photographically on Plates 7A, 5B, 5C, and 5E in his Atlas[53, 54]. The spot is invisible when Linné first enters sunlight and possesses its maximum dimensions at its appearance some hours later (perhaps largest at 357°). It next steadily diminishes and is smallest near 90°. It then enlarges again but at sunset still has not regained its early morning size. The

spot is more diffuse and more hazily outlined under a low sun than near noon, and this aspect is more marked in the morning than in the evening.

We tabulate the results secured by various observers in measuring the Linné spot with a filar micrometer. In order to make all the measures readily comparable, we shall define the *diameter of Linné* to mean the north-south diameter in miles of the outermost edge of the white area. The data for the three former

TABLE V.—DIAMETER OF LINNÉ*

Colongitude	Pickering 1897-8	Barnard 1902-4	Wirtz 1904-6	Haas 1935-9
354°	—†	6.9	—†	9.7
4°	6.3	6.8	5.2	9.7
14°	6.0	6.6	5.0	9.6
24°	5.6	6.4	4.9	9.5
34°	5.4	6.2	4.8	9.4
44°	5.1	5.9	4.7	9.1
54°	4.8	5.6	4.5	8.8
64°	4.5	5.1	4.4	8.5
74°	4.3	4.6	4.5	8.2
84°	4.1	4.3	4.6	8.0
94°	3.8	4.2	4.8	7.9
104°	3.9	4.4	4.9	7.9
114°	4.3	4.8	5.2	7.9
124°	4.8	5.4	5.4	8.0
134°	5.1	5.8	5.8	8.3
144°	5.2	6.1	6.1	8.5
154°	5.3	6.4	6.5	8.8
164°	—†	—†	—†	9.1

*Values corrected for foreshortening. †No observations for this colongitude.

observers are taken from published graphs of diameter against colongitude;[48, 66] my own work consists of measures on 55 dates in 1935, 1938 and 1939 at Mandeville, Alliance, East Cleveland, and Columbus (refer to Table III for telescopes used).

Table V reveals several things of interest:

1. All observers but Wirtz agree that the spot is largest near colongitude 0°.

2. Pickering and Barnard find the spot to be the smallest near 95°; Wirtz and I centre our broad minima near 65° and 105° respectively.

3. Wirtz makes the decrease in diameter from the near-sunrise maximum to the near-noon minimum to be 0.8 miles, but the others agree fairly well on an amount of about 2.3 miles.

4. Wirtz finds the spot to be more than a mile larger near sunset than near sunrise, but the other three agree that it is about 0.7 miles smaller.

5. Barnard and Wirtz make the increase from near noon to near sunset about 2 miles, but Pickering and I here find approximately 1.4 miles.

The agreement among Pickering, Barnard, and me is pleasingly good; Wirtz's more divergent results are perhaps partly due to his unfortunate practice of graphing with the moon's age instead of with colongitude,[56] a method that can produce errors of 8 degrees in colongitude.

The similarity of these variations to the seasonal ones in the polar caps of Mars led Pickering to ascribe them to a similar cause—i.e., to the melting and subsequent depositing of hoar-frost around the craterlet;[54] but as Goodacre,

TABLE VI.—LONG PERIOD CHANGES IN LINNÉ

Observer(s)	*Year(s)*	*Diameter Measured*	*Angular Diameter*	*Reference*
SCHMIDT, BIRT, BUCKINGHAM, WOLF, HUGGINS, JOYNSON, TACCHINI	1866-8	Outermost sunrise	about 7″	48
PICKERING	1897-8	Outermost sunrise	4.9	48
"	1897-8	Outermost noon	2.9	48
"	1897-8	Innermost (brightest portion at) noon	2.1	54
"	1899	Innermost noon	2.0	54
"	1903	Innermost noon	2.8	54
BARNARD	1902-4	Outermost sunrise	5.3	56
"	1902-4	Outermost noon	3.3	56
WIRTZ	1904-6	Outermost sunrise	4.1	56
"	1904-6	Outermost noon	3.4	56
HAAS	1935, 1938-9	Outermost sunrise	7.5	—*
"	1935, 1938-9	Outermost noon	6.1	—*
"	1935	Innermost noon	3.8	—*

*Measures not published previously.

supported by recent temperature-measures,[44] stated,[15], one would expect the hoar-frost to vanish quickly and completely instead of gradually and partially.

We have so far avoided mentioning the *numerical* results of the four observers; my figures greatly exceed those of the three others. Part of this difference is probably due to "personal equation." Nevertheless, we find in the next table excellent evidence that the spot actually varies in size over long periods of time and that after shrinking from 1866 to 1897 Linné has now regained its old outlines.

17. Macrobius. $\lambda+46°, \beta+21°$. Sunrise 314°, noon 44°, sunset 134°.
9 observations. 1 drawing.

By means of a study of this crater[41] McLeod succeeded in confirming in a pleasing manner the appearances on Plates 1, A-E and 3, A-E in the Atlas[53, 54].

Barcroft recently gave some attention to this object and informed me in correspondence that its floor is occasionally, but not usually, strikingly dark.

18. Manilius. $\lambda+9°, \beta+15°$. Sunrise 351°, noon 81°, sunset 171°. 27 observations. 27 drawings.

Figures G and H on Plate XII show the aspect at relative colongitudes 55° and 137° respectively. The coarser changes can be followed on Plates 5, A-E and 7, A-E in the Atlas;[53, 54] and the aspect after colongitude 130° is shown on Mount Wilson Photographs H 10, H 17 (Plate XV), 322, and H 8, the last exhibiting the brilliant east outer wall that brightens very rapidly during the last day in sunlight. Photographs H 10 on August 7, 1925, at 134° and H 17 on October 15, 1927, at 145° (Plate XV) give a materially different aspect to the dark region near the east wall than do my sketches near the same colongitudes in April-November, 1937.

Manilius shows practically nothing not already described. Dark areas in its eastern half are dark in the morning, are lighter near noon, and finally darken rapidly before the approaching sunset shadow; conversely, western dark areas remain very dark after the retreat of the sunrise shadow and are lightest near noon, and some of them are rather dark again in the evening. No mark in this crater is certainly darkest near noon. Under high light rows of tiny bright spots interpenetrate the dark markings. The east inner wall is brilliant at sunrise, and the west inner wall is brilliant at sunset. During most of the lunation a spot on the southeast wall (Figure G) is the brightest mark in the crater. What appears to be a ridge at the foot of the inner walls completely encircles the floor. On May 18, 1937, at 3° the central mountain, which had not been in sunlight long, looked dull. There radiate outward from the walls of Manilius eight broad bands; these are most conspicuous near noon and are very faint under a low light.

19. Messier and *Pickering.** $\lambda+47°, \beta-2°$. Sunrise 313°, noon 43°, sunset 133°. 273 observations. 183 drawings.

Pickering found in these objects striking changes in size and shape, which variations he came to ascribe to surrounding patches of hoar-frost.[48, 52, 65]

We plan soon to devote a separate paper to recent investigations of these craterlets and hence merely remark in passing that much of interest and to some extent corroborative of earlier work has been found and that after 130° the sunset shadows of Messier and Pickering are lighter than those of their neighbours.

20. Mount Huyghens Craterlet. $\lambda-3°, \beta+20°$. Sunrise 3°, noon 93°, sunset 183°. 38 observations. 5 drawings.

Wilson has noted a minute craterlet in the highest peak of Mount Huyghens; the *position* of this object is shown in Figures F and G on Plate XIV. The crateriform nature has been seen visually by Wilson in five different lunations;

*Formerly Messier A.

by Barcroft on May 6, 1941, at 28°; by Vaughn on two dates in 1941; and by me on a number of occasions before 30°. Vaughn has probably had the most distinct view to date, and he confirms Wilson's conjecture that the apparent craterlet may be merely a cup-like depression. This markedly bright object is about a mile in diameter. A high peak stands against its northwest rim.

In 1937 I watched the apparent craterlet under all lighting; I found that after 40° it is seen as a bright spot only and that after 160° it becomes indistinguishable from the rest of Mount Huyghens but at sunset again reveals its true nature.

The question of whether the craterlet has always been as conspicuous as now is of interest. Neison describes what is probably this object as "a very minute crater, hardly discernible even under very favourable conditions."[42] Some other evidence favours a possible recent increase in ease of visibility, but none of it is convincing.

21. Peirce and *Peirce A*. $\lambda+54°$, $\beta+17°$. Sunrise 306°, noon 36°, sunset 126°. 10 observations.

Barcroft reports that these craters become bright spots of decreasing size as the sun rises higher upon them until near noon Peirce A vanishes entirely. Toward evening they are again seen as craters. This behaviour is similar to that of Linné. It is worth mentioning that Birt sometimes could not find Peirce and that Gray and Richards thought Peirce A often "obscured" after 0°.[14]

22. Phocydides Shadow. $\lambda-57°$, $\beta-53°$. Sunrise 57°, noon 147°, sunset 237°. 19 observations.

In six different lunations I have observed that the sunrise shadow in Phocydides is darker and of a different colour than the adjacent shadow in Schickard between 57° and 65°, an appearance also seen by four other former Mount Union students. By 70° the two shadows may be the same darkness, and at sunset they do not differ appreciably.

23. Pico. $\lambda-9°$, $\beta+45°$. Sunrise 9°, noon 99°, sunset 189°. 54 observations. 41 drawings.

On the basis of a study in 1912-5 of the variations in size and brightness of the spots on this mountain, Pickering concluded that they are patches of snow.[59] Especially interesting is a "snow-storm," shown on Plate 9B in the Atlas,[53, 54] at 53°, which he described as extending southward from the northeast end of Pico in the shape of a bright "haze" between 65° and 110°; he declared that while it endures several of the spots are indistinctly outlined.

In 1933-4 Rawstron succeeded in confirming much of Pickering's work but found that the "snow-storm" then began at 35°, was most conspicuous at 60°, and was gone by 130°.[72]

The present observations were made by Johnson and me, largely in 1938-9. The cycle of changes then found is shown by Figure I-L on Plate XII; refer also to Plates 9, A-E in the Atlas[53, 54] and to Mount Wilson Photographs H 10, H 17 (Plate XV), 322, H 8, and H 5.

At sunrise (Figure I) the whole mountain is bright; the east edge is brighter

than the rest, but the brightest mark of all is an apparently detached one northeast of the main mass. The land between it and the main mass is at first extremely dark but gradually lightens to reach intensity 3 at 35°. Meanwhile the rest of the mountain, except perhaps some other dark shadings (Figure I), grows dimmer. Near 65° Mare Imbrium west and northwest of Pico suddenly brightens greatly and thus *seemingly* becomes part of the mountain; the resulting roughly rectangular shape is shown by Figure J. This mass contains several bright spots and dark shadings. After 110° Pico changes again; and on June 15, 1938, at 118° I observed Mare Imbrium west and northwest of the mountain in the process of darkening to its normal condition (Figure K). The result is to make Pico narrow for a day or two near 130°, the east edge perhaps being invisible. The early morning triangular aspect is again present by 140° (Figure L). Bright spots now appear on the west edge. The northeast spot detaches itself from the main mass, and the shading separating them becomes very dark. After 170° parts of the mountain grow brilliant; other parts, extremely dark.

At least some of the bright spots show only the ordinary low-sun or high-sun brightenings. The northeast spot is dullest near noon; but this result is perhaps due to a brilliant west side at sunrise and a brilliant east side at sunset. The dark area between this spot and the main mass is lightest near noon but is dark even then; perhaps it lies in a depressed region and hence is never properly illuminated. The "expanded" outlines between 65° and 110° are similar to *mare*-brightenings around Aristarchus, Messier, and Pickering mentioned previously.

The "snow-storm" of Pickering and Rawstron[59, 72] was seen only once in 1938: on April 11 at 40° by Johnson, who did not discern it on the two following nights. In 1939 I examined the region of the "snow-storm" between 37° and 131° on twenty-five dates; I detected a sinuous narrow bright streak running southeast from the northeast spot, but my streak did not much resemble the broad and hazy band depicted by the two earlier observers. It appears likely that the "snow-storm" was very inconspicuous in 1938-9; this opinion is somewhat supported by the irregular behaviour, on which Pickering and Rawstron commented,[59, 72] of some of the Pico spots.

24. Piton "Riverbed." $\lambda -1°, \beta +42°$. Sunrise 1°, noon 91°, sunset 181°. 36 observations. 1 drawing.

Martz has noted a sinuous bright streak extending from near the north base of Piton to a point a little north of P. Smyth.[22] He could not find this streak on any of the lunar charts in Pickering's library, but it is naturally uncertain how carefully the region had been examined by competent selenographers. Martz's conjecture[22] that this mark is one of Pickering's "riverbeds"[48] is false; one can see from 2° to 22° and near 178° that it is really a ridge, which is dark under very low illumination. Before 30° the west half is brighter than the east half. The ridge fades steadily during much of the lunation, and is very vague near 160°.

25. Plato. $\lambda -9°$, $\beta +51°$. Sunrise 9°, noon 99°, sunset 189°. 73 observations. 34 drawings.

The map of the floor by Beer and Maedler[73] differs so much from the present appearance that the only alternative to supposing that those observers could not draw is to infer great changes during the last 100 years. The first thorough survey of the spots, of which at least the larger are craterlets, on the floor was carried out by Elger, Gledhill, Pratt, and others in 1869-71; a subsequent study by Allison, Gray, and Williams in 1880 revealed several changes in the visibility of the craterlets as compared with 1869-71.[15] In 1892 Pickering made a detailed examination of the floor in the excellent seeing of Arequipa and, on the basis of further changes in conspicuousness of the spots and streaks, concluded that there is more volcanic activity in Plato than in any area of the same size on the earth.[48] Molesworth studied the floor in 1896-7[15] and mapped a craterlet first seen by Mee in 1891.[50] Wilkins has reported his 1936-9 survey, by means of which he detected six craterlets not recorded previously.[59] In 1931 Goodacre summarized work up to that time as follows:[15] "(1) The floor of Plato gradually darkens as the altitude of the sun above its horizon increases from 20° till after full noon. (2) That the light spots and streaks vary in visibility from time to time independent of the solar altitude or libration. (3) That the surface is occasionally subject to total or partial obscuration due to mist or clouds resting upon it and so blotting out details usually visible."

Figure A on Plate XIII is a map of Plato based on the 1935-40 observations of Martz, Johnson, Barcroft and me. Since it depends upon a qualitative study of drawings instead of upon micrometric measures, it is inferior in quality to maps founded on the latter. It exhibits the general appearance of Plato near noon but is not intended to represent the aspect under any specific illumination.

Our group has seen the craterlets only as spots, which are most prominent under high lighting. The sharp outlines of some of the craterlets on Mount Wilson Photographs H 8 and H 5 near sunset on Plato demonstrated the high quality of those photographs. Some of our spots are brightest under low illumination, but such ones may be hills. Incidentally, Johnson found the spots larger relative to Plato with a magnification of 71× than with 213×; and on September 17, 1940, with seeing 8-10 I perceived them to be much smaller than they usually look. The relative conspicuousness of the craterlets is indicated by numbers on the map; when two or more of them appeared equal, all were given the same number. Determining the exact rank was difficult, especially for the fainter spots; moreover, those brightest under low illumination have higher numbers than their conspicuousness at noon would earn them.

Two examples of possible change in the craterlets during the period 1935-40 are:

1. The Craterlet 12 north of Craterlet 2 (Figure A on Plate XIII) was not seen by me in 1935 but was perhaps rather outstanding to Martz the next year. In 1940 I saw 12 much more readily in some lunations than in others.

2. Craterlet 1, nearly in the centre of Plato, has usually been the most conspicuous[48, 78, 80] and was observed to be thus in 1935-9 and in March-April, 1940. In June 1940 however, I found it only equal to Craterlet 2 and during the next three months thought it distinctly fainter than the latter. For example, in 1940 I recorded on April 23 at 99° that "the central craterlet is much more conspicuous and much more sharply outlined than the others" but on July 20 at 97° tha "the central craterlet is not the most conspicuous." Some doubt is cast on the reality of any change, though, by the fact that in August-November, 1940, Johnson and Barcroft each called Craterlet 1 the most conspicuous spot on the floor. Probably Craterlet 2 is really Pickering's "large white blurred area" near this position.[48]

Under a high light Plato contains a network of bright streaks; these develop in the forenoon and fade in the afternoon much as do the spots.

The floor is very dark near sunrise and sunset and much lighter near noon; it lightens rapidly during the first two days in sunlight and darkens rapidly during the last two days in sunlight. It is true that these statements directly contradict the results of many skilled observers about a darkening as noon approaches,[15, 48, 78] but our observations are completely incompatible with such a darkening. I think that this effect is an error caused by comparing the floor to regions such as neighbouring portions of Mare Imbrium and Mare Frigoris, as Pickering did;[48] these areas are not constant in intensity but vary much as Plato does. Under a high light an intricate pattern of vague dark shadings covers the floor. As the map indicates, the edges of the floor are darker than the rest, perhaps because the floor is so convex that its edges are never properly illuminated. The shadings and the edges are both brightest near noon.

We find in Plato, most plainly near 35° and 175°, the familiar darkening of bright ridges receiving their first or last rays of sunlight.

At sunrise two hazy bands are present between the long shadows of the west-wall peaks; there follows a list of all observations (my own with the one exception noted) before 15°, arranged according to the sun's elevation h above a point on the floor at $\lambda - 9°$, $\beta + 50°$:

1. September 22, 1939. h, 1°.5 and 1°.7. The positions of the marks in question are given by Figure B on Plate XIII. "There are two strange-looking hazy bands about 2 in intensity in the shadow. The bands are not of uniform darkness, nor are their edges linear." They were first seen at 0^h45^m, h, 1°.4. Note the difference in darkness between the east and west portions of the shadow (Figure B).

2. September 22, 1939. h, 1°.9. "The bands are now seen to be simply sections of the floor between the very long shadows of the west-wall peaks."

3. June 14, 1940. h, 1°.9. "There are present two hazy streaks of intensity 5 (or 4.5), in which is much complex detail."

4. September 22, 1939. h, 2°.1. "The bands are no longer notable while the shadows of the peaks are marked."

5. August 8, 1935. *h*, 2°.2. A drawing shows no bands, perhaps because of a hazy sky.

6. June 14, 1940. *h*, 2°.3. "The two hazy streaks are now lighter and rather delicate; they appear to be blending in with the rest of the floor."

7. August 12, 1940. *h*, 2°.5. "Two hazy streaks are present; they are complex in structure and vaguely bounded."

8. June 28, 1936. *h*, 2°.9 and 3°.2. No bands were noticed when the colour of the floor was examined.

9. November 19, 1939. *h*, 3°.1. Barcroft noted no bands while observing Plato.

10. November 12, 1937. *h*, 3°.4. Same as 8.

11. February 16, 1940. *h*, 3°.6. "None of the appearances seen on September 22, 1939, is present."

12. March 2, 1936. *h*, 4°.0 and 4°.3. Same as 8.

The hazy outlines of the bands and the fact that nothing at all resembling them is seen in their positions under other lightings suggest strongly that they represent a local lunar atmospheric effect.

An examination of some of the literature on Plato *after* the above observations had been made was instructive. Webb wrote:[78] "Bianchini, Short, and Elger have seen some *longitudinal bright streaks* at lunar sunrise." Elsewhere he declared:[78] "J. Adams (*Eng. Mech.*, No. 2374) noted on two occasions near sunrise, *when the interior was filled with shadow*, that *two beams of light* traversed two-thirds of the floor from the W. wall resembling searchlights; they were parallel and well-defined [conspicuous?] and *had the appearance of passing through a slight vapour* resting on the surface." (The italics are mine.) The fog-suggesting appearances remarked by Neison, Klein, Elger, and Williams[15, 78] also merit mention. However, nothing abnormal can have been present on August 30,* 1892; for Pickering on that date made a micrometrical study of some of the craterlets[48] and would surely not have neglected to report on anything abnormal that then existed.

26. Plinius. $\lambda+23°$, $\beta+15°$. Sunrise 337°, noon 67°, sunset 157°.
135 observations. 82 drawings.

The changes are indicated by Figures D-F on Plate XIII.

Goodacre said:[15] "The interior contains a very bright central mountain-visible at all times. This mountain is complex and under certain angles of il, lumination presents the appearance of a double crater." He later remarked of a drawing:[16] "The well-known double central crater is seen standing out of the shadow." He further declared that[15] "under a high light" the central mountain "resembles a large crater with a dark interior." MacDonald has reported[37] the work of F. Lamech, who found the central mountain to contain two curved formations, of which neither was a craterlet.

I once saw the pair of seeming craterlets at 348°, but usually near 350°

*Date by G.M.T.

I find instead two round spots *not* resembling craterlets. By 355° an ellipse is forming (Figure D); the two spots and a connecting band are now merged into the brighter and thicker southern arm, but the northern arm and the detached spot east of the southern arm are new developments. By 5° the northern arm has brightened and thickened to achieve equality with the southern, and the latter has advanced eastward so that the formerly detached spot is now a knob on its end. The resulting high-sun aspect, shown by Figure E and by Plate 5A at 358° in the Atlas,[53, 54] is Goodacre's "high light" one and lasts until about 80°. Meantime the arms of the ellipse are steadily thickening at the expense of the "dark interior," a process beginning no later than 52° and perhaps as early as 25°. From 80° to 105° we see a solid mass of almost uniform brightness; but there is a small dull area in the centre, and the west edge is slightly the brightest part. Near 110° the interior of the elliptical mass darkens so that the edges become the brightest portion, the west edge being brightest of all. At about 125° the bright edges begin to resolve themselves into three bright spots on the corners of the mass, a process shown by Mount Wilson Photograph H 10 at 134°. These three bright spots on a mass otherwise of intensity 4, as seen near 140°, are shown on Figure F and on Mount Wilson Phctograph H 17 (Plate XV). The shadow of the central mountain now reveals that its west edge rises well above the floor. The edges brighten somewhat and the interior darkens a little between 140° and 148°, when the sunset shadow covers the mass. Martz presumably saw this final aspect when he recorded on August 7, 1936, at 146°: "The central mountains . . . appear to consist of *two or three very close* mountain peaks."

These changes take somewhat different courses from one lunation to another; we give two examples:

1. On November 10, 1937, at 350° I observed that: "The central mountain is *an ellipse*, open at the east-southeast. . . . There is *a sort of knob* at the east end of the south arm; this knob is *not separate* from the rest of the ellipse." Surely these words reveal *more advanced* development than the following entry fourteen hours *later* in the lunation on April 18, 1937, at 357°: "The central mountain consists of *two peaks*. . . . The ellipse has *not yet* formed."

2. Compare Figure F, a drawing on October 4, 1936, at 134° and this description ten hours *later* in the lunation on July 27, 1937, at 139°: "The central mountain is *a solid ellipse slightly brighter* at the west edge and along the east edge than at the centre. The centre is *still bright*, however; though there is some *slight darkening* in places."

So striking a cycle of changes and such irregular behaviour certainly merit further investigation.

Goodacre wrote:[15] "Under a high light Plinius . . . resembles a wheel, the outer rim being narrow and bright with four broad fan-shaped spoke-like markings, equally spaced and running to the centre." Martz, Roth, and I have all drawn these "spokes"; but they are really composed of separate bright spots (Figure E). The individual spots are brightest near noon and faint or absent under a low sun.

Note the two bright external ray-splotches shown coming from spots on the wall in Figure E. Martz detected eight such areas, the most conspicuous being the one associated with the pair of craterlets on the east inner wall.

Plinius also exhibits a brilliant east inner wall at sunrise, a brilliant west inner wall at sunset, a few transient low-sun darkenings, and some high-sun dark shadings.

27. Pythagoras Shadow. $\lambda -65°$, $\beta +63°$. Sunrise 65°, noon 155°, sunset 245°. 6 observations.

The sunrise shadow in this crater may be darker than others in the vicinity before 71° but is probably normal after 73°, more observations being desired.

28. Riccioli. $\lambda -74°$, $\beta -3°$. Sunrise 74°, noon 164°, sunset 254°. 61 observations. 44 drawings.

Figure C on Plate XIII, Mount Wilson Photograph 322, and Plate 15C in the Atlas[53, 54] show the usual appearance of the dark area in the north part of this crater.

Pickering has described the great rapidity with which the dark area develops just after sunrise.[48] I have twice observed Riccioli for several hours in succession at the proper colongitude for studying this phenomenon, with the following results:

At 75°.2 the entire floor is very dark, intensity 1, and is covered by a multitude of ridges, craterlets, etc., of which details Johnson made three good drawings on September 19, 1937, average colongitude 77°.5. At 76°.4 the dark area is still unformed, but its general outlines are suggested; the north part of the floor is now 1.5 in intensity while the south and central parts are 2.5. By 76°.8 the dark area is assuming its typical form, and the south part of the floor is 3. Thirty-five minutes later the inner portions of the dark area are fading out, and the south section of the floor has lightened to 4. By 78°.4 the dark area has its typical aspect except for minor details, and no further appreciable changes affect it until after 240°.

The south tip of the area (Figure C on Plate XIII), about 3.5 in intensity at 240°, has brightened to 6 by 246°; at 252° the west edge is also 6, and apparently shadow has entered on the east side. We have seen that sunset brightenings regularly affect west inner walls; and it is hence natural to suppose that the dark area occupies a shallow depression, an aspect Barcroft and I have detected near 77°.

Barcroft concluded from observations on successive nights in September 1940 that the dark spot darkens steadily from 83° to 170°; but I have found little change in intensity in this interval. It is desirable that others should investigate the alleged darkening.

At the Case Observatory I measured the north-south length of the dark area with a micrometer on three dates and obtained 34″ or 39 miles.

29. Stevinus Shadow. $\lambda +54°$, $\beta -32°$. Sunrise 306°, noon 36°, sunset 126°. 56 observations. 1 drawing.

On March 20,* 1893, when Stevinus and its neighbour Snellius were on the terminator and full of shadow, Pickering noted that the interior of the latter was far darker than that of the former, an appearance he attributed primarily to sunlight reflected into the shadow of Stevinus.[48] From a study of Pickering's original observations of Stevinus near sunrise I found that he consistently discerned a coppery tint to the Stevinus shadow between 305° and 310° and at no other time.[59] Our group's early observations have already been published.[51] Subsequent study has revealed that:

1. The two shadows vary too little in *colour* for the difference to be profitably studied.

2. The Stevinus shadow is distinctly *lighter* than the Snellius shadow up to 309°.

3. The Stevinus shadow is distinctly *darker* than the other from 313° on, an aspect shown by Plate 2A at 322° in the Atlas.[53 54]. Since Stevinus has higher walls than its neighbour,[15] it will hold detectable shadow longer than Snellius can and will exhibit a larger shadow at a given time.

4. The sunset shadows are normal until 115°, but the one in Stevinus is probably subsequently the darker.

The morning shadows evidently reverse their relative darkness near 311°, a figure so close to the 310* when Pickering ceased to detect the copper hue that we can hardly doubt that it is related to the darkness. Whether the change is a darkening of Stevinus or a lightening of Snellius or both is uncertain.

30. Theophilus. $\lambda+26°$, $\beta-12°$. Sunrise 334°, noon 64°, sunset 154°. 48 observations. 40 drawings.

From a study of the changes occurring each lunation in the size and brightness of the central peaks Pickering inferred the deposition and melting of snow on and around them.[62]

The cycle of changes indicated by recent observations, chiefly by me in 1938, is shown in Figures G - K on Plate XIII, where some of the peaks have been lettered for convenience in reference.

When the sun first strikes the peaks *a* is brilliant, brightest at its west edge and dimmest at its north edge. Peak *b* is also bright, being dimmest at its south and east ends; and three drawings near 340° give it the shape shown by Figures J and K on Plate XIII. By 345° the south arm is apparently gone; and *b* appears as in Figure G, the western of the two ridges (such they appear to be) running southward from it, perhaps being the vanished south arm. Peaks *c* and *d* are dark when first illuminated and never become conspicuous.

As the lunation advances peak *a* grows dimmer, but the relative brightness of its parts does not alter; *b* seemingly advances northeastward because of the brightening of marks there (Figure H), the process perhaps beginning near 355° and ending near 30°.

The shadows (all are omitted in Figures G, J, and K) of *a* and *b* (including

*Date by G.M.T.

the eastern extension) are still perfectly black at 5° but have lightened to the tone of the floor by 25°. While fading they preserve their former shapes; e.g., we see in Figure H at 22° that the lightened shadow of *a* continues to indicate by its hump a peak on the southeast shoulder of that mountain.

Peak *a* and the west part of *b* grow duller; not long after 0° the south half of *a* is seen to be brighter than the north half. Other changes also occur, and by 45° the aspect shown in Figure I is present. The peaks form an enclosed roughly triangular area with *a* at the northwest corner and *b*, which is brightest at its west end, along the south side. The land enclosed is 2 in intensity in its western part, which is one of those areas darkest near noon, and 3 in its eastern part.

Still present at 86°, this high-sun aspect is gone by 106°. The difference in brightness between the north and south halves of *a* vanishes, perhaps as early as 80°. At 115° *b* has its sunrise shape (Figure J). The enclosed area is distinctly lightened by 106° and the same as the floor of Theophilus by 123°. The peaks now begin to cast shadows, which are preceded by the usual darkenings.

As sunset approaches, most of *a* remains of intensity 6, but the north and west ends grow duller. A bright spot appears on the southeast shoulder near 135° and is 8 or more by sunset (Figure K). A spot behaving similarly develops on the east end of *b*. Low-sun darkenings appear, particularly on the south arm of *b*. Mount Wilson Photographs H 17 (Plate XV) and H 11 and the famous, Yerkes photograph[62] show well the appearance at and after 145°. On June 21, 1935, near 148° I watched the peaks while the sunset shadow of the east wall was rapidly approaching them and observed that they grayed considerably in only 30 minutes.

These changes are mostly ordinary low-sun and high-sun brightenings, the alterations in *b* being the most surprising ones. This peak perhaps varies differently in different lunations after 125°. The intensity of the portion of *b* nearest *a* shows unusual alterations: it is about 7 near 340°, is fading and 5.5 at 25°, is 7 again by 35°, but is dimmer after 100°.

After finishing the above study I consulted Pickering's published drawings[42] and found such amazingly great differences from my own, even after allowing for differences in observers, telescopes, stations, and seeing and for the difficultness of these objects that I was forced to infer vast changes in Theophilus between 1916 and 1938. It is highly desirable that other observers investigate the present appearance of the peaks. In 1940 I three times *at the telescope* directly compared the appearance to Pickering's drawings,[63] with these results:

September 15. 72°.1. "The peaks certainly resemble more my 1938 drawings near this colongitude than Pickering's sketch at 72°.4. Of his brilliant E-shaped mark nothing can be seen."

August 18. 89°.2. "A comparison of the appearance to Pickering's drawing at 87°.3 reveals differences."

August 20. 114°.0. "The appearance is similar to Pickering's drawing at 111°.5 but can hardly be exactly the same."

It is very much worth while to mention the striking and irregular variations in size Bolton found in his craters J, K, and L at the foot of the northwest inner wall.[5]

Martz has observed that some areas on the east inner wall are brilliant at 337° and much fainter two days later.

31. Timocharis "Vapour." $\lambda -12°$, $\beta +27°$. Sunrise 12°, noon 102°, sunset 192°. 11 observations.

Barcroft reports that near full moon Timocharis is filled with "vapour" of the sort Pickering studied in Schroeter's Valley[48, 54] so that the crater's outlines are far less distinct than those of its neighbours, this "vapour" extending westward toward Archimedes for some distance and then turning off to the *south*. The "haziness" begins at 60°, is conspicuous near 100°, and is gone by 150°. At 152° Barcroft has noted that the rays of Timocharis[15] extend westward and then turn off to the *north*.

Mount Wilson Photographs H 12, H 17 (Plate XV), H 10, 322, H 8, H 5, and H 9 supply good views of the "haze," support Barcroft about its conspicuousness near 100° and absence after 150° and about the increased distinctness of the rays in this region after 145°, and indicate that the structure of the "vapour" is very complex. Less detailed but compatible photographic views are given on Plates 9, A-E and 11, A-E in the Atlas[53, 54], on two photographs by Wilson, and on two more by Martz.

32. Triesnecker—Hyginus Region. $\lambda +5°$, $\beta +6°$. Sunrise 355°, noon 85°, sunset 175°. 5 observations.

Midway between Hyginus and Agrippa and near the famous Hyginus Cleft lies a conspicuous dark area of complex structure. Goodacre asserted:[15] "... on the E. side of the Mountain [Hyginus] M is a large circular dark spot on which I have detected two bright spots, probably crater cones." Webb's reference to probably this dark spot is interesting:[78] "... at Quadratures, there is near 93 [Hyginus] a large blackish spot, covering two ranges of hills and the vale between. Here B. and M. [Beer and Maedler], most unprejudiced if not oppositely prejudiced witnesses, admit a variation of colour not dependent merely on the angle of reflection, and possibly connected with changes like those of our seasons."

A *winding* cleft extending southeastward from this dark area to the system of *straight* clefts west of Triesnecker is not shown in the Paris Observatory Photographic Lunar Atlas[55] nor in Pickering's Atlas[53, 54], and it is also absent from Fauth's drawings[12] and from Goodacre's sectional map.[15] Wilson thinks that it may be present on some 1919 Mount Wilson photographs and recorded it photographically himself on June 6, 1939, at 4°. On July 9 that year, near 48°, McLeod noted: "The cleft in question is plainly visible with both 150× and 210×. It is more conspicuous in the telescope than in the [Wilson] photograph." I saw this winding cleft with difficulty on August 4 at 5° and could not even suspect it on three other nights in 1939, probably because of poor seeing or improper illumination. Whether the cleft actually appeared between 1901

(Pickering) and 1919 (Mount Wilson) is uncertain because the earlier photographs are inferior to the Mount Wilson ones and because the former visual observers may have overlooked this mark; but it appeared desirable to give the details above, the more so in view of the appearance of the dark spot Hyginus N in this vicinity reported by Klein as a new mark in 1878 *after he had been familiar with this part of the moon for 12 years.*[10]

33. Tycho. $\lambda -11°$, $\beta -43°$. Sunrise 11°, noon 101°, sunset 191°. 16 observations. 4 drawings.

On July 14, 1940, at 3^h3^m, colongitude 20°.6, my attention was strikingly drawn to an appearance on the shadowed east outer wall. I recorded: "A curious faint milky-looking luminosity . . . is seen. . . . These luminous marks in the shadow are ragged-edged and of an irregular shape." At 3^h55^m I remarked: "The marks affected by this 'luminosity,' even if natural surface-features, are certainly hazily outlined at present." The next night at 32° I observed: "The shadow is gone from the east outer wall of Tycho; and the marks there 'luminous' last night now appear to be 'natural' features but still look much as yesterday." On December 9, 1940, at 26° Barcroft found "some luminosity on the east rim or the east outer slope." Other observations by him and me establish that:

1. Nothing unusual is seen as late as 16°, presumably because the ridges later "luminous" are not yet struck by the sun's rays.

2. The "luminosity" is present by 21°.

3. The phenomenon gradually loses its conspicuousness. The ridges are unmistakably less sharp than other detail in the vicinity at 26°. Their true nature is evident by 31°. They subsequently grow very faint, though I once noted as late as 57° that they are still hazily outlined.

The marks in question may be seen on Plates 10A, 12A, and 10B in Pickering's Atlas[53, 54] at 30°, 36°, and 53° respectively and can be distinguished with difficulty on a few photographs by Wilson and Martz near 25°. The whole visual appearance strongly suggests a local lunar atmospheric effect, as with the Plato floor-bands.

In view of Birt's remarks about a mistiness in Tycho for some years[14] it is important to mention that Barcroft finds the floor ill-defined at times. Both observers comment on the irregular visibility of detail on the floor.

34. Vieta Shadow. $\lambda -56°$, $\beta -29°$. Sunrise 56°, noon 146°, sunset 236°. 5 observations.

My observations in five different lunations show that the sunrise shadow in Vieta is darker than neighbouring shadows between 62° and 67° but is like them by 73°.

35. Zuchius Shadow. $\lambda -50°$, $\beta -61°$. Sunrise 50°, noon 140°, sunset 230°. 4 observations.

Though normal at 198°, the sunset shadow in Zuchius is darker than others in the vicinity after 214°.

(*To be Continued*)

PLATE XVI

DOMINION ASTROPHYSICAL OBSERVATORY
VICTORIA, B.C.

(Haro Strait and San Juan Island in distance).

REPORT OF THE DOMINION ASTROPHYSICAL OBSERVATORY, VICTORIA, B.C.

For the Years 1940 and 1941

J. A. Pearce, *Director*

(With Plate XVI)

1. *Staff:* The deaths of our two senior Astronomers are chronicled with deep regret. Canada lost two distinguished scientists and the staff sustained irreparable personal losses when Dr. W. E. Harper, Director from 1935-1940, died on June 4, 1940, and Dr. J. S. Plaskett, Founder and Director, 1917-1935, died on October 17, 1941. Intimately associated for over thirty years at the two Canadian Government Observatories, their numerous and important researches in stellar motions received worldwide recognition. Biographical sketches of both astronomers have been published in various scientific journals.

The degree of Doctor of Philosophy was conferred on K. O. Wright by the University of Michigan, March, 1940, the subject of his thesis being "A Study of Line Intensities in Four Solar-Type Stars." Dr. R. M. Petrie was elected a Fellow of the Royal Society of Canada in May, 1940. Dr. A. McKellar was granted leave of absence to lecture in physics at the University of British Columbia during the academic year 1941-42. Miss L. M. Blake, stenographer for the past thirteen years, was retired April 1, 1941, and Miss E. M. Dunn was temporarily appointed to the position. Mr. Hugh Little, who served faithfully as caretaker for the past twenty-two years, died on October 14, 1940. Mr. H. W. Dukeman was appointed to succeed him. Miss Phoebe Riddle, B.A., of Victoria, and Dr. C. G. Patten of the College of the Pacific, Stockton, California, spent one month each year as voluntary assistants.

2. *Instruments:* The two-year period has been characterized by an expansion of our instrumental equipment, within the limited funds available, and a number of new instruments have been acquired which will greatly facilitate the spectrographic and photometric researches.

Dr. McKellar has designed a vacuum chamber for the alumin-

ization of our 72-inch mirror. This steel tank has an inside diameter of 84 inches, a height of 58 inches and with its 96-inch base-plate weighs approximately three tons. It was constructed by Yarrows Ltd., shipbuilding firm of Esquimalt, B.C., during the past fall. Pressure tests, at approximately three atmospheres, were successfully run in December, and the vacuum chamber delivered to our workshop. The work of preparing the apparatus for the aluminizing of our principal mirror will be undertaken this spring. Two diffusion oil pumps recently constructed by Mr. S. S. Girling have been added to the aluminizing equipment, and certain necessary apparatus, such as a five-ton chain hoist has been acquired.

With a view to increasing substantially the resolving power of our stellar spectrograph, Beals and McKellar successfully carried out some experiments with a model of a proposed Littrow-form instrument. The results, which were very encouraging, indicated that a very powerful, effectively six-prism, instrument of excellent performance could be obtained with only slight modification to our existing spectrograph. Furthermore, the Littrow-form permits the most efficient use of the two Wood aluminium-on-glass gratings, for researches in the visual and red regions of the spectrum. The construction of this instrument by Mr. S. S. Girling has been commenced but it is not expected that the spectrograph will be completed for several months.

A new instrument has been designed by Dr. Beals and constructed by Mr. S. S. Girling. This instrument derives, by mechanical graphical methods, the profiles of spectral lines from microphotometer tracings, and thus intensity measurements can be made in one-tenth the time required by the usual computational methods. Our spectrophotometric investigations will thus be greatly accelerated by this ingenious labour-saving machine.

Dr. Petrie supervised the conversion of the Bamberg micrometer into a projection measuring machine and our two projection instruments have been installed in a newly-constructed suitably-darkened room, thus greatly facilitating the measurement of spectra for radial velocity and wave-lengths.

The optical system of the registering microphotometer was improved by the installation of new mountings for certain optical parts and the introduction of a new system for the auxiliary plate

illumination. A scale for direct reading has been added, in order that measurements of the continuous spectrum, required in colour temperature investigations, may be expedited. A new photographic dark room adjoining the microphotometer room has also been constructed.

A number of changes and modifications were made in connection with the telescope and dome. The motorization of the Cassegrain focussing mechanism was effected by the installation of a 1/3 h.p. A.-.C. motor, 1800 r.p.m. with a reduction gear ratio of 120 to 1, which gives one revolution of the focussing rod every four seconds. The controls for this operation were incorporated into the guiding control box. A 1/4 h.p., 220 v. A.-C. motor was installed in the telescope to operate the steel disphragm covering the 72-inch mirror, formerly operated manually. The telescope was completely rewired for the thermostatic control of the mirrors in order to prevent their fogging during the winter months.

The 2500 feet of 1/2-inch steel cable used to operate the shutters, the wind curtains, the observing platform, and to turn the dome, was renewed. The aluminum painted dome has been repainted dark brown which blends with the background and makes the building inconspicuous.

A portable 6-inch reflector on an altazimuth fork mounting of duralumin, constructed by Shaw and Hopkins of Victoria, B.C., has been acquired. Additions to the workshop equipment include a South Bend screw-cutting lathe with accessories, a drill press and motor grinder.

The reforestation of the hill was continued by planting some 600 spruce and 100 fir trees supplied by the Forestry Department of the Provincial Government. In addition some 30 dogwood and maple trees have been planted between the office building and the dome. A system of subterranean pipes to service these trees has been installed.

A gasoline-driven portable pump with 1200 feet of hose was added to the fire-fighting equipment.

The necessary maintenance of the buildings and road has been efficiently carried out by the Public Works Department.

3. *Current Observing Programmes:* Extensive investigations which

will require some years for completion are in progress. The programmes include the following:

(*a*) Studies of the class B stars fainter than the 7th magnitude, north of the celestial equator, by Pearce and Petrie. Approximately 40 per cent of the observing time of the telescope is devoted to this programme with which Wright and Stilwell are materially assisting.

(*b*) The radial velocities of 150 A- and B-type stars previously studied at Victoria, and requiring further observation.

(*c*) The investigation of the dynamical and physical properties of spectroscopic and eclipsing binaries, by Petrie and Pearce.

(*d*) Investigations of the Wolf-Rayet, P Cygni and emission-line stars, by Beals.

(*e*) Studies of the R- and N-type stars brighter than the 9th magnitude having north polar distances less than 100°, by McKellar.

(*f*) The determination of the colours, with the photoelectric photometer, of several hundred distant stars has been initiated by Beals.

(*g*) An investigation of spectral line intensities in solar-type stars, employing high dispersion, is being pursued by Wright.

4. *Spectrographic Binary Investigations:* The following orbital studies have been completed.

(*a*) The orbit of θ^2 Tauri was determined from 78 spectrograms, many of them made with high dispersion, by Petrie. The elements of this very eccentric orbit ($e=0.76$) are in agreement with those deduced by Plaskett, at Ottawa, in 1915, with the exception that the systemic velocity of the earlier orbit is 4 km./sec. more positive than that found by Petrie. His value of V_0 is in exact agreement with that predicted from the motion of the Taurus cluster, of which this star is a member. The difference must be ascribed either to a real change in V_0 or to instrumental effects.

(*b*) Thirty-two high-dispersion spectrograms of κ Cancri (H.D. 78316) form the basis for a re-determination of the orbital elements by Pearce and Miss P. Riddle. The preliminary elements found by Ichinohe at the Yerkes Observatory (1904-07) are in excellent agreement with the recent Victoria elements but the reported secondary spectrum does not appear upon our phorographs.

(*c*) The orbits of the components of the double-lined A0 binary H. D. 207650 were determined by Petrie from 36 high-dispersion

plates. The small amplitudes ($K_1+K_2=77$ km./sec.) and high eccentricity ($e=0.53$) made the determination of the velocity curves difficult. The components are much alike in mass and radius and are typical of stars of this spectral type.

(*d*) During the past season an orbit for the single-lined B9 star H. D. 34762 was computed by Stilwell from 28 observations. A comparison with a preliminary orbit, computed by him from 28 earlier observations, at the David Dunlap Observatory, led to a revision of the period. As no relative systematic errors were evident, all observations were combined to derive the most probable elements for this binary.

(*e*) A circular orbit for the double-lined A-type binary H. D. 203858 was computed by Patten and McKellar from 29 observations. The absolute magnitudes of the components were determined spectrophotometrically.

(*f*) An orbit for H. D. 207826, Boss 5620, was computed by McKellar and Patten based upon 51 single-prism spectrograms. The orbit is almost circular but a small eccentricity is indicated. The period is very accurately determined due to the long interval covered by the observations.

(*g*) A fourth orbit for the eclipsing variable TX Ursae Majoris was computed by Pearce from 50 single-prism observations secured recently; with the exception of the longitude of the apse, the elements e, V_0, and K were found to be invariable, when compared with his earlier orbits of this system.

(*h*) A thorough investigation of the orbit of AR Cassiopeiae has been made by Petrie. The 67 early Allegheny spectra were remeasured for a new determination of the 1908-09 elements. Revised elements were computed from the 1934-35 Yerkes observations. Thirty-four plates, obtained at Victoria and the University of Michigan, form the basis of a third set of elements for the years 1933-36. Finally, an accurate orbit for 1940-41 was derived from 30 observations secured here. With the exception of the longitude of the apse, no secular changes are in progress.

(*i*) One of the most interesting orbits computed during this period is that of the double-lined A2 binary H. D. 23277, investigated by Petrie. The maximum relative radial velocity of the components never exceeds 50 km./sec. and orbital elements could be

derived only because the sharp spectral line components could be separated with high dispersion. Absolute dimensions were reduced from a determination of the relative brightness of the components, spectrophotometrically.

(*j*) The recently announced 8-magnitude eclipsing variable H. D. 227696, spectral type B2k, was investigated by Pearce and accurate elements were derived from 25 single prism spectrograms secured in 61 days. Spectral-line profiles of Hγ and λ4471 from six plates at selected phases led to a value of $\Delta m = 0.52 \pm 007$, which permitted the calculation of the absolute dimensions and masses. The binary is a very massive system, $K_1 = 182$ km./sec., $K_2 = 237$ km./sec., $m_1 = 16.7\odot$, $m_2 = 12.8\odot$ and $R_1 = 6.6\odot$, $R_2 = 5.2\odot$. The principal minimum at J. D. 2427242.87, observed by Ashbrook photometrically, is in precise agreement with that predicted by the spectrographic orbital elements.

Observations are practically completed for the following binaries and the measurement of the plates, in most cases, is fairly well advanced:

H. D. 17034; 19356; 35715; 37043; 37756; 43246; 47129; 110533; 144208-9; 156247; 156633; 180939; 181987; 191201; 193536; 198846; λTauri; π^4Orionis; oLeonis; ωUrsae Majoris; 25 Serpentis; σCygni; δCapricorni; and ιPegasi.

The following stars are under observation:

H. D. 1383; 25799; 100018; 131511; 190967; 195987; 217888; 225257; RS Arietis; AB Persei; RW Tauri; RX and RY Geminorum; HR 4016; AW Herculis; S Equulei; VW, XX, and XZ Cephei.

5. *Apsidal Motions:* During the past six years, Pearce and Petrie have given considerable attention to the discovery and spectrographic determination of apsidal motions in binary systems. The former has announced advancing apsidal motion for RZ Cassiopeiae, period 18.3 ± 1.2 years and for 57 Cygni period 25.4 ± 0.3 years. Two additional systems have been thoroughly studied recently, AR Cassiopeiae and TX Ursae Majoris.

From the four orbits, previously mentioned, Petrie has determined an apsidal period of 435 ± 125 years for AR Cassiopeiae. While the photometric work of Stebbins in 1920-21 indicated a shorter period, theory would predict a period of the order of 400 years in agreement with spectrographic results.

The 83 spectrograms of TX Ursae Majoris were secured over short time intervals at the four epochs, 1925, 1932, 1934, and 1940 by Pearce. A simultaneous solution of all observations yielded the following results for the elements.

Year	ω	T
1924.940	189.0 ± 6.5	J. D. 2424128.8745 ± 0.0499
32.206	266.2 ± 8.6	6782.3633 ± 0.0819
34.101	277.7 ± 3.5	7474.6968 ± 0.0252
40.276	342.3 ± 1.6	9729.8829 ± 0.0131

$e = 0.162 \pm 0.0043$

$V_0 = -10.9 \pm 0.16$ km./sec.

$K = 54.3 \pm 0.20$ km./sec.

$T = \text{J. D } 2415019.422 \pm 0.011 + 3.0633175\ E \pm 0.0002356 \pm 0.0000028\ (T - T_0)$

$\omega = 295.8 \pm 4.48 + 10.1 \pm 0.12\ (T - 1900)$ $\qquad P' = 35.6 \pm 0.42$ years

The early type binaries systems of short period and large mass which, on present knowledge, should exhibit precessional apsidal motion are being investigated. Theory would indicate that the massive system H.D. 227696 should have an apsidal period of approximately ten years, and it is proposed to derive spectrographic elements biennially. These studies will ultimately form a test of present theory and advance our knowledge of stellar structure.

6. *Spectrophotometric Studies of Binaries:* The first programme designed to supply quantitative values of the light-ratios in double-lined spectra has been completed by Petrie. From the profiles of the spectral lines secured at particular phases the light-ratios may be deduced. A test of the method on six eclipsing variables gave results in good agreement with the values derived from the light curves. The light-ratios for 16 double-lined binaries have been determined, thus permitting the orbital inclinations and the absolute dimensions of the systems to be found. This work will have an important bearing upon the determination of the masses of binary systems and will contribute new observational evidence to the mass-luminosity relation. A new programme embracing all suitable objects brighter than visual magnitude 7.5 north of the equator has been initiated.

Line profiles and spectrophotometric gradients of the β Cephei star H. D. 199140 have been determined by Petrie. More than 300

spectrograms of this interesting pseudo-cepheid have been measured for radial velocity. The observations extend over four years and changes in the velocity curves from year to year are apparent. The curves are characterized by a "stand-still" on the descending branch at the point of maximum compression of the pulsating body. A small but definite change in period has been established; at the present time the period is lengthening. The form of the spectral line profiles is found to vary over the five-hour period of radial-velocity variations. These peculiarities show that the star is not a spectrographic binary but a true β-Cephei object.

7. *Photometric Researches:* The electrical system of the stellar photometer has been rebuilt, resulting in improved insulation and shielding, and is now ready for use in an extended programme of stellar colour measurements. This instrument, designed by Beals, has been tested by him upon certain stars for which colour temperatures were measured at Greenwich, with satisfactory results. In order to calibrate this photometer a programme of some 50 stars of all spectral types is being observed jointly by Beals and Petrie. The former is measuring the colours with the photometer by means of suitable filters, while the latter is determining spectrophotometric gradients photographically. Preliminary results indicate a high order of accuracy and reproducibility for the photometer colours. Upon completion of the calibration, all of the stars measured at Greenwich for colour temperature will be observed.

8. *Spectrophotometry of Solar-Type Stars:* Using the three-prism spectrograph and a Wood, bright first-order, grating, spectra extending from λ4028 to λ6752 have been obtained for the four solar-type stars, the sun, γCygni, αPersei, and αCanis Minoris. Detailed measurements of the equivalent widths and intensities of about 600 spectral lines have been made by Wright. Turbulent velocities and excitation temperatures have been obtained as follows:

Star	Type	Turbulent Velocity	Γ/ν	Excitation Temperature
Sun	dG0	1.5 km./sec.	3.5×10^{-6}	4400°±100° K
γCygni	cF8	6.6 "	3.5	5375°± 75° K
αPersei	gF5	5.8 "	5.2	6275°±150° K
αCanis Minoris	dF5	2.1 "	3.0	5275°±150° K

The temperatures of the two dwarf stars were found to be lower than those of the two giant stars. A comparison of the radial velocities for the enhanced and neutral lines confirms Adams's results that the former usually give a more positive velocity.

9. *Wolf-Rayet, P Cygni and αCygni Stars.* During the past two years Beals has observed as many P Cygni stars in the northern hemisphere as possible, to obtain spectrophotometric measures of the line profiles and the velocities of the absorption and emission features. The main purpose of the research has been to clarify the general characteristics of the P Cygni spectrum and to establish relationships between these early-type stars. The results suggest the existence of a definite sequence which appears to have definite physical relationships with the novae, the correspondences extending both to the character of the emission-line spectra and the corresponding values of temperature and diameter.

Beals has continued his observations of the peculiar spectrum variables, H. D. 41511, 45910, 51480, 190073 and 207757. Sufficient plates of each star have been obtained to provide reliable data for intensity and velocity measurements. The detailed analysis of the spectrum of H. D. 190073 is completed and ready for publications. The results may be briefly summarized as follows:

The hydrogen line profiles can be interpreted as due to: (*a*) An underlying reversing layer with physical characteristics similar to that of an ordinary A-type star giving rise to a broad winged absorption line, and (*b*) An envelope of outward moving atoms of relatively large diameter giving rise to a P Cygni-type profile which is superimposed upon the broad line.

Certain features of the hydrogen line profiles have been interpreted as due to self-reversal in the envelope and it is shown that the most favourable conditions for self-reversal occur when the ejected atom received a large initial impulse close to the stellar surface and is subsequently slowed down by the gravitational field to a velocity which may approach zero at great distances from the star.

The peculiar Ca II profiles are also interpreted in terms of an envelope of ejected atoms. It is demonstrated that the duplicity of the displaced absorption component can be explained as a result

of an appropriate relationship between the velocity of the atom and its distance from the star.

The emission component of the Ca II profile is shown to be subject to self-reversal and reasons are advanced for believing that the corresponding absorption takes place at a distance from the star which is large relative to the radius of the shell responsible for the displaced P Cygni absorption.

From a consideration of values of the velocity of escape at different distances from the stellar surface radii are computed for the various Ca II shells. The results indicate a radius of $5.6r_*$ for the most displaced component of the Ca II profile, $3.4r_*$ for the emission component and a radius of the order of $1000r_*$ for the self-reversal. A similar computation for the hydrogen lines leads to a value of $10r_*$ for the emission envelope. Reasons are given for believing that these represent maximum values.

10. *Interstellar Lines in Early Type Stars:* Dr. Beals' programme of the interstellar calcium and sodium lines in early type stars is practically completed. The majority of the observations of the sodium lines were made with the three-prism spectrograph using "agfa super-pan" press films. Considerable attention is being paid this season to the group of stars in Monoceros, which are difficult to observe from Victoria because of their position in the sky.

11. *Identification of Interstellar Molecular Lines:* From a detailed study of the spectra of diatomic molecules, McKellar idenfied the sharp interstellar absorption lines observed by Adams and Dunham at λλ4300.3, 3874.6 and 3934.3 as one of the molecule of CH, CN, and NaH respectively. The first of these identifications has been tentatively advanced by Swings. A search was made with the Victoria three-prism spectrograph to detect fainter predicted lines of these molecules, but our instrument did not possess sufficient resolving power to reveal them. Using the powerful Coude spectrograph of the Mount Wilson Observatory, Dr. Adams found in the spectrum of ζOphiuchi the three new interstellar lines of CH and two lines due to the CN molecule predicted by McKellar on the basis of the above identifications. Thus conclusive evidence was obtained for the existence of diatomic molecules, in particular CH and CN, in interstellar space. From the nature of the observed

molecular absorption it was shown that the "rotational" temperature of space where the absorption takes place is about 2°K.

Struve and Elvey have shown the presence of Hydrogen, Nitrogen and Oxygen in space by observing emission lines of these elements in Milky Way regions. The elements now known to exist in interstellar space are: Hydrogen, Carbon, Nitrogen, Oxygen, Sodium, Potassium, Calcium, Titanium and Iron.

An extensive table has recently been prepared by McKellar giving the wave-lengths arising from the lowest states of about thirty of the more commonly occurring diatomic molecules composed of at least one cosmically abundant atom. These are the interstellar lines to be expected if the molecules under consideration are present in sufficient quantity in interstellar space. A discussion of all the work on interstellar molecular absorption up to April, 1941, is included in the publication, "Molecular Lines from the Lowest States of Diatomic Molecules Composed of Atoms Possibly Present in Interstellar Space", which is in press.

12. *Laboratory wave-lengths of the CH Band:* Several plates of the CH band secured with the 21-foot grating spectrograph of the University of California, having a dispersion of 0.62 A/mm., were measured by McKellar to determine the best laboratory wave-lengths. A critical examination of all published laboratory wave-lengths of the CH lines was made, in connection with the work of interstellar CH.

13. *Recalibration of Standard Lamps:* The Observatory possesses four standard ribbon-filament tungsten lamps whose colour temperatures for various operating currents were determined by Dr. W. E. Forsythe of the General Electric Laboratories some 15 years ago, and which are to be used in a number of studies involving heterochromatic photometry. Through the courtesy of Professor F. A. Jenkins, University of California, a quartz standard lamp recently manufactured by Kipp and Zonen of Delft, Holland, and calibrated at the Physical Laboratory of Utrecht, was used to recalibrate the tunsten lamps.

The comparison was carried out photographically. Spectra were taken of the four lamps operating at temperatures of approximately 1650°K, 2050°K, 2500°K, and 2650°K. The relative photographic densities were measured at numerous wave-lengths with the micro-

photometer in the direct reading form. The results showed that no measurable systematic differences existed between the calibrations of the lamps performed by Forsythe some 15 years ago, and the quartz lamp recently calibrated by Kipp and Zonen. Calibrated lamps are now available for spectrophotometric researches.

14. *R- and N-Type Stars:* Dr. McKellar has continued his observations of the R- and N-type stars. He observed that the hitherto unindentified bands in the blue-green and blue regions of the spectra of some eight or ten N-type stars occur with very great strength in the spectrum of RY Draconis. Wave-length measurements of these bands from several spectra of the same star exhibit certain regularities in wave-number differences that may aid in the eventual identification of the bands. These stellar bands do not appear to be the same as any molecular bands yet produced in the laboratory.

The "Lithium" Star WZ Cassiopeiae: In spectrograms of the N-type variable star WZ Cassiopeiae, covering the far red spectral region, a strong absorption line was observed at λ6708. This line, which is exceeded in strength only by the extremely intense sodium *D*-line absorption has been identified by McKellar as the resonance doubtlet of Li I, the lithium analogue of the sodium *D*-lines. Up to the present time the only extra-terrestrial evidence of the presence of the element lithium has been that found in the solar spectrum. Hence the present observation yields the first evidence of the occurrence of lithium outside our earth and the sun. Other N-type stars so far examined do not exhibit the lithium line so it is thought that in the atmosphere of WZ Cassiopeiae this metal must be unusually abundant. Further study of the λ6708 line in this "lithium" star is being carried out, particularly to examine whether the intensity of the line varies with the star's brightness.

15. *Spectrum of Comet Cunningham (1940c)*: Nine spectra of this relatively bright comet were obtained. The dispersion in the region of the λ3883 CN band was 57 A per mm. and the projected slit-width 0.8 A, the latter corresponding to the greatest purity with which a cometary spectrum has yet been photographed. The λ3883 CN band showed some new and very interesting structural details. McKellar is making a photometric study of the plates in order to examine the interesting hypothesis recently advanced by Swings to

explain the anomalous intensity of certain members of the cometary CN bands.

16. *Papers, Seminars and Popular Addresses:* During the two-year period, a total of 23 research papers were presented before scientific societies, 27 staff seminars were conducted and 56 illustrated popular addresses were delivered. A considerable number of the talks were given to officers and men of the armed services in the Victoria area.

17. *Contributions to the War Effort:* The staff of the Observatory has contributed to the National War Effort in various ways. At the request of the Officer Commanding the Officers' Training Centre, Victoria, B.C., a course of weekly lectures on Practical Astronomy has been given by Dr. R. M. Petrie. Mr. W. H. Stilwell was engaged for ten weeks in a geodetic survey required by the Department of National Defence. Dr. A. McKellar has been loaned to the Department of Physics, University of British Columbia, in order that one of their staff might engage in special radio research for the National Research Laboratory. Technical advice and assistance has been given in the care and renewal of searchlight reflectors. A number of signalling and searchlight mirrors were aluminized for the Naval and Military forces.

18. *Seismographic Service:* Under the supervision of Dr. K. O. Wright, the two photographically registering Milne-Shaw seismographs and the antiquated Wiechert vertical instrument were maintained. A total of 247 earthquakes were recorded in 1940 and 261 recorded in 1941. Epicentres were computed for a few severe shocks and details announced to the press.

19. *Time Service:* The maintenance of the Observatory's clocks and time service was carried out by Mr. W. H. Stilwell. Time signals were daily impressed upon the seismograms and local time distributed upon request.

20. *Library:* Dr. Wright supervised the library and prepared the books for the bindery. During this period accessions totalled 185, and 160 books were bound.

21. *Publications:* Publications of the Observatory were distributed as follows:

Vol. VII, No. 11, "The Spectrographic Orbital Elements of H.D. 23277"—by R. M. Petrie.

Vol. VII, No. 12, "The Determination of the Magnitude Difference Between the Components of Spectroscopic Binaries"—by R. M. Petrie.

Vol. VII, No. 13, "The Spectrographic Orbit of H.D. 207826 (Boss 5620)"—by A. McKellar and C. G. Patten.

Vol. VII, No. 14, "The Spectrographic Orbits of H.D. 207650"—by R. M. Petrie.

22. *Bibliography.*

C. S. BEALS

"An Astronomical Trip to Paris," This JOURNAL, vol. 34, p. 15, 1940.

"The Future of the Earth", *Ibid.*, vol. 34, p. 256, 1940.

"On the Physical Characteristics of the Wolf-Rayet Stars and Their Relation to Other Objects of Early Type", *Ibid.*, vol. 34, p. 169, 1940.

"John Stanley Plaskett", *Ibid.*, vol. 35, p. 401, 1941.

"The Photoelectric Cell as the Sensitive Element in Microphotometry", *Pub. Ast. Soc. Pac.*, vol. 52, p. 267, 1940.

"On the Physical Relationships Between Emission Line Stars of Early Type", (abs.), *Ibid.*, vol. 52, p. 278, 1940.

"On the P Cygni Characteristics of H.D. 190073 and the Dimensions of its Emitting and Absorbing Shells", (Abs.), *Am. Ast. Soc.*, Cleveland Meeting, Dec. 1941.

A. MCKELLAR

"Evidence for the Molecular Origin of Some Hitherto Unidentified Interstellar Lines", *Pub. Ast. Soc. Pac.*, vol. 52, p. 187, 1940.

"The Excitation of Molecular Bands in Cometary Spectra", (abs.), *Ibid.*, vol. 52, p. 283, 1940.

"Intense λ6708 Resonance Doublet of Li I in the Spectrum of WZ Cassiopeiae", *Ibid.*, vol. 52, p. 407, 1940.

"Wave Lengths of the CH Band Lines", *Ibid.*, vol. 52, p. 312, 1940.

"The Problems of Possible Molecular Identification for Interstellar Lines", (Abs.), *Ibid.*, vol. 53, p. 233, 1941.

"The Spectrographic Orbit of H.D. 207826 (Boss 5620)", (with G. G. Patten), *Publ. Dom. Astroph. Obs.*, vol. VII, p. 239, 1940.

"A Recalibration of the Standard Lamps of the Dominion Astrophysical Observatory", (with R. M. Petrie), This JOURNAL, vol. 35, p. 337, 1941.

"Band Lines Arising from the Lowest States (Possible Interstellar Lines) of the More Common Diatomic Molecules", (Abs.), *Proc. Roy. Soc. Can.*, vol. 35, p. 173, 1941.

"The λ6708 Resonance Line of Li I in the Spectrum of the N-type Variable Star, WZ Cassiopeiae", *The Observatory*, vol. 64, p. 4, 1941.

"The Structurs of the λ3883 CN Band in the Spectrum of Comet Cunningham (1940c)", (Abs.), *Pub. Ast. Soc. Pac.*, vol. 53, p. 235, 1941; (Abs.), *Proc. Roy. Soc. Can.*, vol. 35, p. 173, 1941.

J. A. PEARCE

"Apsidal Rotation of TX Ursae Majoris", (Abs.), *Pub. Ast. Soc. Pac.*, vol. 52, p. 287, 1940.

"William Edmund Harper, 1878-1940", *Pub. Ast. Soc. Pac.*, vol. 52, p. 231, 1940; *Proc. Roy. Soc. Can.*, vol. 35, p. 117, 1941.

"The Spectrographic Orbit of H.D. 78316", (with Phoebe Riddle), (Abs.), *Am. Ast. Soc.*, vol. 10, p. 65, 1940.

"The Massive Eclipsing Binary H.D. 227696 (Abs.), *Ibid.*, Cleveland Meeting, Dec., 1941.

"The Eclipsing Variable, TX Ursae Majoris", (Abs.), *Proc. Roy. Soc. Can.*, vol. 35, p. 171, 1941.

R. M. PETRIE

"The Atmospheres of the Planets", This JOURNAL, vol. 34, p. 137, 1940.

"The 1940 Transit of Mercury", (with H. Boyd Brydon), *Ibid.*, vol. 35, p. 6, 1941.

"A Recalibration of Standard Lamps of the Dominion Astrophysical Observatory", (with A. McKellar), *Ibid.*, vol. 35, p. 337, 1941.

"The Spectrographic Orbit of θ^2 Tauri", (Abs.), *Pub. Ast. Soc. Pac.*, vol. 52, p. 286, 1940.

"Observations of Spectral-Line Intensities in Spectroscopic Binaries", (Abs.), *Am. Ast. Soc.*, vol. 10, December Meeting, 1940.

"Spectrographic Orbital Elements of H. D. 23277", *Publ. Dom. Astroph. Obs.*, vol. VII, p. 199, 1940.

"The Determination of the Magnitude Difference between the Components of Spectrographic Binaries", *Ibid.*, vol. VII, p. 205, 1940.

"The Spectrographic Orbit of H.D. 207650", *Ibid.*, vol. VII, p. 245, 1940; (Abs.), *Am. Ast. Soc.*, vol. 10, p. 65, 1940.

"Orbital Elements and Apsidal Motion for AR Cassiopeiae", (Abs.), *Proc. Roy. Soc. Can.*, vol. 35, p. 173, 1941; (Abs.), *Pub. Ast. Soc. Pac.*, vol. 53, p. 237, 1941.

W. H. STILWELL

"The Spectrographic Orbit of H.D. 34762", (Abs.), *Am. Ast., Soc.*, Cleveland Meeting, Dec. 1941.

K. O. WRIGHT

"Profiles of the Sodium *D*-Lines in the Spectra of Four Solar-Type Stars", (Abs.), *Pub. Ast. Soc. Pac.*, vol. 52, p. 405, 1940.

"Victoria Observations of the Transit of Mercury, 1940", This JOURNAL, vol. 35, p. 1, 1941.

"Summer Evenings with the Stars—Victoria", *Ibid.*, vol. 35, p. 438, 1941.

"Radial Velocities of Four Solar-Type Stars", (Abs.), *Proc. Roy. Soc. Can.*, vol. 35, p. 171, 1941.

Dominion Astrophysical Observatory,
Victoria, B.C.
January, 1942.

REVIEW OF PUBLICATIONS

Publications of the University of Pennsylvania—Astronomical Series. Vol. V, Part III, and Vol. VI, Parts I-V. Philadelphia, University of Pennsylvania Press, 1941.

This series of publications of the Flower Observatory presents contributions in three important research fields. In the first of these (Vol. V, part III), by the Director, C. P. Olivier and others, the results of nearly ten years of accurate photometry with a wedge photometer and the 18-inch visual refractor are tabulated. These consist of the establishment of the fundamental magnitudes and the positions of the 575 comparison stars in the fields of 52 variable stars, and nearly 3,500 observations of 31 variable stars. This great task has been a continuation of Olivier's work on standardization of the magnitudes of the comparison stars as used by the amateur and professional observers of the A.A.V.S.O. Visual observations of variable stars is a field in which Dr. Olivier has been active for over forty years.

In Vol. VI, parts I-III, P. H. Taylor and R. S. Alexander present very accurate light curves, based chiefly on visual photometry, of the three eclipsing binaries AD Andromedae, V343 Aquilae and ER Orionis. In each case the orbital elements were derived. In Part V Taylor and Olivier study the eclipsing binary EZ Aquilae.

In Vol. VI, part IV, R. H. Wilson, Jr., makes a careful investigation of the use of an interferometer with the 18-inch refractor for the measurement of the position angles and separations of a number of close double stars. He rediscusses the theory of the double star interferometer, describes the construction of the form of the instrument he found most satisfactory for his telescope, and from long series of observations, sets down general rules as to the types of double stars for which the interferometer is especially advantageous. A catalogue of double star results is included.

F. S. H.

Books on the Weather for Amateurs

A list of books on the weather for amateurs, prepared by Alvin Thiessen, Librarian of the Canadian Meteorological Services.

Botley, C. M. *The air and its mysteries.* London, Bell and sons, 1938. 15s.
A highly entertaining account of many interesting weather phenomena.

Great Britain. Meteorological office. *The weather map.* 3d ed. London, 1939. 75c.
A brief, precise description of the methods of making weather observations and of forecasting weather by means of the synoptic map.

Haurwitz, B. *The physical state of the upper atmosphere.* 2d rev. ed. Toronto, Royal astronomical society of Canada, 1941. 75c.
An authoritative book for amateurs and professional scientists on northern lights, meteors, luminous clouds and other interesting phenomena in the stratosphere and the ionosphere.

Minnaert, M. *Light and colour in the open air.* London, Bell and sons, 1940. $3.75.
A book of interest to artists and physicists, as well as to those who have eyes and see not. Helpful in training in acurate habits of observation.

Petterssen, S. *Introduction to meteorology.* New York, McGraw-Hill, 1941. $2.50 (U.S.)
The best elementary textbook on the subject of meteorology: weather and climate.

Shaw, Sir Napier. *The drama of the weather.* 2d ed. Cambridge, at the University Press, 1939. 10s. 6d.
A pleasing review of weather lore.

Stewart, G. *Storm.* Toronto, Macmillan, 1941. $3.00.
An exciting novel in which the weather does thrilling things. Everybody will enjoy this book.

U.S. Civil aeronautics administration. *Meteorology for pilots,* by B. C. Haynes. Washington, 1940. 75c.
An elementary account of meteorology, well suited to the needs of experienced pilots.

U.S. Dept. of agriculture. *Climate and man.* Washington, 1941. $1.75.
An inexpensive and comprehensive survey of weather and climate, theory and practice, the whole world over. Elementary and excellent. This well-bound copiously illustrated book contains more than twelve hundred pages. Should be in every library.

U.S. War department. *Weather manual for pilots.* Washington, 1940. 40c.
The best and fullest summary of what every pilot may know about flying weather.

U.S. Weather bureau. *Codes for cloud forms and states of the sky.* Washington, 1938. 15c.

A book that teachers in public and high schools will find useful, because it gives accurate descriptions and good photographs of many cloud types. A miniature cloud atlas.

U.S. Weather bureau. *Forecasting from synoptic weather charts*, by RICHARD HANSON WEIGHTMAN. Washington, 1940. 10c.

Interesting to the amateur and helpful to the professional forecaster.

U.S. Weather bureau. *Forecasting weather*, by GEORGE S. BLISS. Washington, 1940. 10c.

A very elementary pamphlet on the subject of weather forecasting written for the layman.

WENSTROM, W. H. *Weather and the ocean of air.* Boston, Houghton Mifflin Co., 1942. $4.50.

An authoritative book on the new science of weather directed expressly to the general reader. Contains instructions for the installation of meteorological instruments in the home.

Many readers will like the following book, which, unfortunately, is not yet available in Canada. The Ryerson Press, Toronto, is agent for the publisher.

BENSTEAD, C. R. *The weather eye.* London, Robert Hale, 1941. 8s. 6d.

An irreverent discourse upon meteorological lore, ancient and modern, with many indiscreet references to the art of forecasting as now practised. . .

Hark I hear the asses bray.
We shall have some rain today.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Help, instead of Hindrance, from a Difficulty

The war has necessitated many modifications in university schedules. Daily military training in the late afternoons at the University of Alberta has rendered unavailable the four and five o'clock periods for other activities. Whatever the limitations that are imposed they are willingly accepted for they involve a very minor contribution to the general war effort. But, in one case at least, from what appeared to be a difficulty there arose a solution which has advantages that might never have been visualized if the difficulty had not been encountered.

The astronomy class for 1941-42 was scheduled for ten o'clock on Tuesdays, Thursdays and Saturdays, and this involved a time-table conflict for one of our honour students. An attempt to find another regular hour that would suit everybody proved futile, and finally the solution adopted was to meet on Monday and Wednesday evenings at seven o'clock, and on Saturday mornings at eight.

The following features of this schedule are worth noting:

1. It made possible the taking of the course by special students—city teachers, for example.

2. It provided opportunity for sky observation without arranging special meetings for the purpose. At the same time it allowed for activities which require a daylight hour.

3. The evening classes were over by eight o'clock, and thus they did not interfere with other evening engagements.

A summary of some of our experiences may be of interest. During the short days we had many opportunities as a class of observing the sky for a few minutes at a time, and noting its evolution as the weeks went by. With the introduction of Daylight Saving the mornings were shorter and one day we observed Venus at the morning class with the telescope just as the stars were disappearing. On the other hand by the end of the term we were observing the sun with the telescope at both the morning and evening classes.

As a result of these experiences it has been decided for the coming year to adopt the same schedule by choice.

J. W. Campbell.

University of Alberta,
June 3, 1942.

MEETINGS OF THE SOCIETY

AT TORONTO

December 2, 1941.—The Society met in the McLennan Laboratory, University of Toronto, at 8.00 p.m., Dr. D. W. Best in the chair.

Three persons were duly elected to membership in the Society, viz.:

Charles Bertwick, 57 Glenwood Avenue, Toronto;
John R. Bird, 231 Westwood Avenue, Toronto;
Fred H. Hallman, 26 Spring Street, Waterloo, Ont.

Dr. F. Shirley Patterson then addressed the members on "Other Milky Ways." Distributed fairly uniformly over the whole sky the telescope reveals thousands upon thousands of "other universes," spiral nebulae which are systems of stars similar to our own galaxy. Some of these nebulae are grouped in clusters, numbering from two or three up to more than one hundred. Most of them contain Cepheid variables, open and globular clusters and star clouds. In many the photographic plate reveals dark clouds of obscuring matter such as is believed to exist in our own Milky Way and which prevents us from seeing the nebulae beyond in that region of the sky.

When the astronomer looks at these island universes he wants to sort them out and analyze them into various types: elliptical, normal spiral and barred spiral. They are so far away that their distances cannot be determined by the parallax method and other means have to be used: (1) study of Cepheid variables in the nebulae, (2) relation of brightness of novae to apparent magnitude, and (3) the red shift in the spectrum. A regular programme is being undertaken at the new Palomar observatory to seek supernovae in these nebulae by photography with the Schmidt camera. The photoelectric cell is used to measure the light of these extragalactic nebulae.

Dr. Patterson presented the following "recipe" for such an island universe or "other milky way": Take some tens of thousands of millions of stars of assorted sizes, weights and colours, weigh them; weigh out an equal portion of dark gas, dust and meteorites; add a dash of luminous gas and set the whole spinning. It must spin rapidly, completing one turn every 200 million years or so. This means a velocity of 750,000 miles per hour at the point 2/3 of the way from the centre to the edge. After the spinning has been going on for about 3000 million years, the mass should become a flattened pin-wheel with relatively few lumps remaining, except perhaps at the centre where most of the material has congregated. Now step back a distance of about 700,000 light-years and admire your milky way. It should be a glorious pin-wheel when looked at flat on, but might resemble, from the side, a gigantic, star-studded fried egg viewed edge on.

Dr. Helen S. Hogg then presented the fifth in her series on "Explorations in Clusters and Nebulae," dealing with luminous diffuse nebulae. About 20 years ago it was discovered by Hubble that in all nebulae of the diffuse type there is a direct relationship between the dark or bright gaseous nebulae and the stars contained in them. Where the nebula shows an emission spectrum, the

involved star is hot and of early type; those which have a continuous spectrum are lighted by simple reflection. Stars in nebulae with continuous (reflection) spectrum, such as the Pleiades, are nearly all of class B1 or later; stars in nebulae with emission spectrum (example, the Orion Nebula) nearly always have spectra earlier than B1. A definite red nebulosity, 0.4 mag. redder than the surrounding sky, is observed around the red super-giant star Antares and may be seen by powerful binoculars if Antares is placed behind an obstruction. Nebulae illuminated by B stars are 0.24 mag. bluer than the sky and cannot be observed visually. These diffuse nebulae absorb some of the bright ultraviolet light from the star embedded in them and re-emit it as a bright line of their own. The emission spectrum depends on the temperature of the star in the nebula. Antares lights up the nebulosity for a radius of about 30 light-years, while our feeble sun would illuminate a nebula for only one-fourth light-year radius.

Diffuse nebulae are very irregular, having no clear-cut boundaries, and thus distances are difficult to determine by direct trigonometrical parallax. Indirect methods indicate the Orion nebula is between 500 and 1000 l.y. distant, and thus about 100 l.y. diameter. These nebulae show extreme tenuity, better than the "perfect vacuum" of the laboratory. They are composed of hydrogen, helium and "nebulium," the latter of which has been shown to be oxygen and nitrogen in a peculiar, highly ionized state. Many of the common elements probably exist as dust or rock matter but their presence is difficult to determine.

No certain evidences of structural changes, proper motion or rotational motion have been observed in most of the diffuse nebulae. In 1894, a radial velocity of +17 km./sec. was observed in the Orion Nebula by Keeler at the Lick Observatory and this was later confirmed by photographic methods. Although there seems to be a decided turbulence with different areas moving at slightly different speeds, there is no evidence for rotation of the mass as a whole, but the time interval is too short. Some evidence may be obtained in the course of years. In a few cases a noticeable variation has been observed such as in the fan-shaped nebulae with a variable star or suspected variable at the tip. These all seem to be in dark lanes or gaps presumably filled with non-luminous material. In such there appears to be no outward or other movement of formation. The problem faced by astronomers is to decide whether the diffuse nebulosity around a star is (1) a residue of the ordinary contraction process, (2) is it now in process or being emitted, or (3) is the star simply passing through a region of diffuse matter?

FREDERICK L. TROYER, *Recorder.*

February 3, 1942.—The Society met in the McLennan Laboratory, University of Toronto, at 8.00 p.m., Dr. D. W. Best in the chair.

Miss Ruth J. Northcott, David Dunlap Observatory, then spoke on "Pathways to the Stars." In her address she described how amateurs could best use the Society's annual OBSERVER'S HANDBOOK. Miss Northcott described in detail the many phases of astronomical information to be found in the various tables and maps, and the use of the tables of phenomena.

Dr. Helen S. Hogg then gave the sixth in her series of short talks on

"Explorations in Clusters and Nebulae," dealing with the so-called planetary nebulae. Although they have no connection with planets, she said, these nebulae were so named because they showed a similar apparance in small telescopes. Small and clear cut, they possess a more or less definite spheroidal or annular symmetry. The centre of these objects is nearly always a fairly luminous star. The planetary nebulae give a faint emission spectraum.

Although planetary nebulae are many times larger in volume than the solar system, fewer than 150 of the objects have been found. Dimensions range from .02 up to .95 light years diameter, compared with .0014 light year for the diameter of the solar system at the orbit of Pluto. Outstanding examples of planetaries of interest to amateurs are M1, the Crab nebula; M27, the Dumbbell nebula; M59, the Ring nebula in Lyra, and M97, the Owl nebula. Averaging less than 1′ in apparent size, the largest known is NGC 7293 which extends over an area 15′ x 12′. The more distant appear as stellar objects in even the largest telescopes.

The planetary nebulae are distributed throughout the galaxy, but with a marked concentration in the Milky Way from 18h to 20h R.A. Their shapes range from annular types with a circular or elliptical ring through various gradations to a circular or elliptical disc without discernible structure. Proper motions appear small, indicating great distance. These range from 500 to 18,000 parsecs. The central star usually shows surface temperatures of 20,000°K to 125,000°K. Some planetary nebulae exhibit internal motions, greater towards the centre, which is interpreted as a motion about the axes.

No changes have been observed in these objects, with one exception, but a long time interval would be required to observe changes. There is a definite outward radial motion in the Crab nebula, a borderline type of planetary nebula, where an expansion of some 800 miles per second has been observed. This may possibly be the expanding shell of an old supernova seen by Chinese observers in this region in 1054 A.D.

Definitely in a class by themselves, planetary nebulae do not fit in with accepted theories of stellar evolution. They must be regarded as an exceptional and rare branch of cosmical evolutional development, doubtless of catastrophic origin. As they are fewer in number than 0.01 per cent. of the total stars, it is difficult to explain why they are so few if they are actually remains of old novae or supernovae.

Mr. J. R. Collins exhibited a lantern slide enlargement of a recent Mount Wilson Observatory photograph of the Sagittarius region taken in both blue and red light. The photograph, from *Science Service*, demonstrated how photography of the region in red light brought out several times the number of stars obtained on the ordinary plate in blue light.

FREDERIC L. TROYER, *Recorder.*

AT OTTAWA

February 16, 1942.—A meeting of the Ottawa Centre was held jointly with the Ottawa Section of the Society of Chemical Industry. Dr. E. F. Burton, Head of the Department of Physics, University of Toronto, described "The Electron Microscope." The meeting was held in the lecture hall of the National Research Laboratories.

The human eye is capable of seeing point sources of light. The smallest diameter that can be seen by reflected light is about 1/250 inch, because this at the minimum distance of 10 inches subtends at the eye the minimum angle of 1.4 minutes of arc. The micriscope is used to view objects of a diameter much less than 1/250 inch, and to bring them to at least the minimum apparent distance of 10 inches. Owing to the lengths of the waves of visible light, the ordinary microscope, no matter how expensive, will enlarge only 500 diameters. Further enlargement for ease of viewing brings forth no greater detail. In other words, the limit of the ordinary microscope is about 2,000 A., or about 1/125,000 inch.

The electron microscope, owing to the fact that electron wave motions are very much smaller than wave motions of visible light, is able to resolve down to a diameter of about 350 A. The commercial application of this new instrument awaits only the solution of manufacturing details. The potential force used to accelerate the electron beam is 45,000 volts and must be kept constant within a volt for good photography. The picture may be viewed on a fluorescent cathode-ray screen, the focussing being accomplished either electromagnetically or electrostatically, depending on the design. A number of slides illustrated the possible use of the electron microscope.

Dr. C. Greaves, President of he Chemical Society, introduced the speaker, while Mr. F. W. Matley, President of the Ottawa Centre, R.A.S.C., tendered the formal vote of thanks.

MALCOLM M. THOMSON, *Secretary.*

April 10, 1942.—Members and friends of the Ottawa Centre enjoyed an interesting evening meeting at the Dominion Observatory.

The Dominion Astronomer, and his associates, had open house with all divisions on display. He and the society president, Mr. F. W. Matley, met the guests informally in the centre hall.

In the basement, the Seismological Division had a demonstration of earthquake recording instruments, and several actual records. The Solar Physics Division displayed its Coelostat camera used in observing sun-spots, and on the ground floor had several pictures and charts showing sun-spots and their relation to rainfall and plant and animal life.

Members of the Time Service Division explained how precise time is determined from star observations, stored with precise astronomical pendulums, and made available to the public by means of the Time Machine. Several interesting electrical devices were also explained. The Nixon Planetarium,

the Foucault Pendulum, and the Library completed the list of displays on the ground floor.

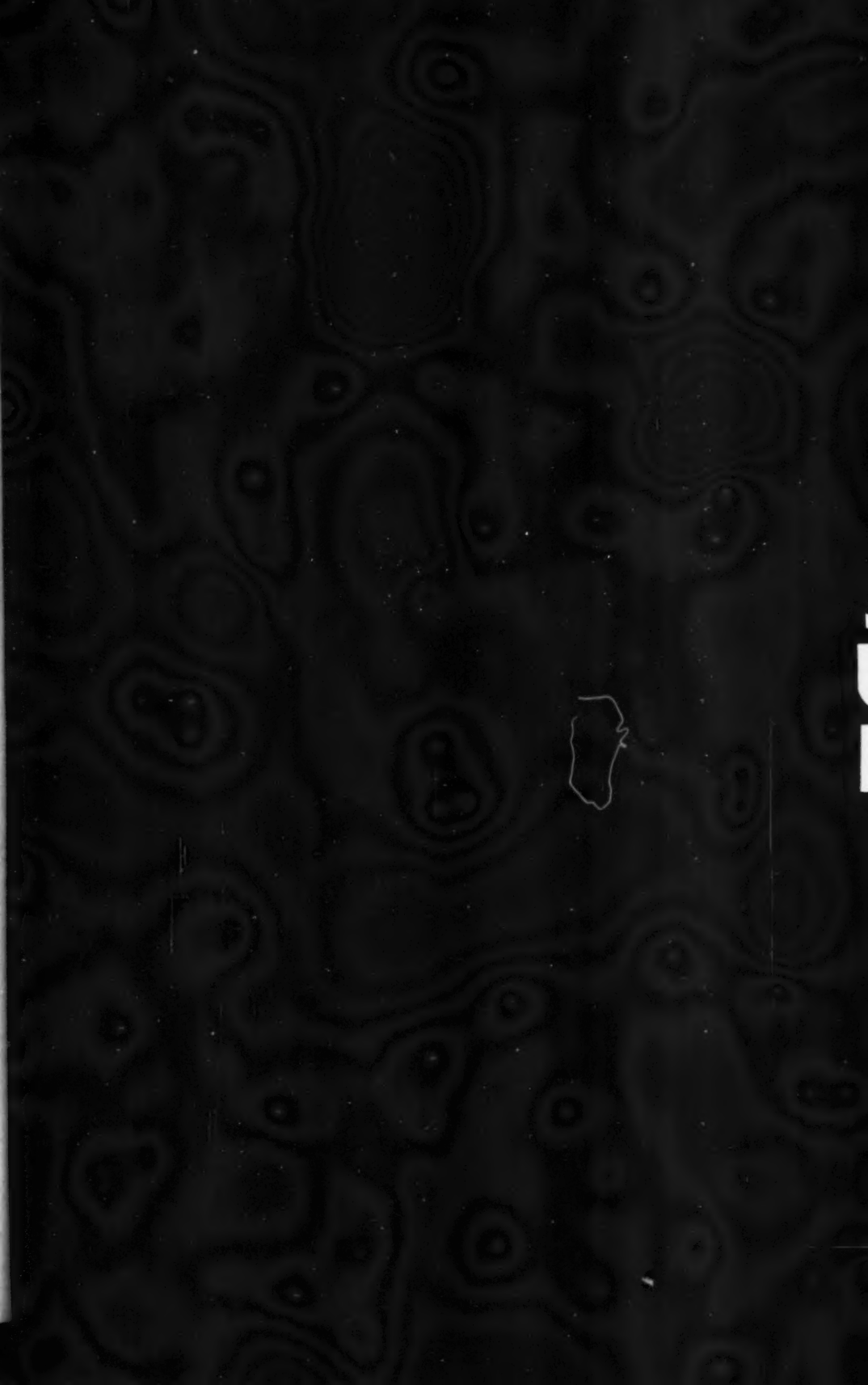
Upstairs, the Magnetic Division had a liberal showing of instruments and charts describing the work that is being carried on across Canada. Determination of variations in magnetic compass bearings are highly important to the war effort, particularly in air navigation.

The Astrophysical Division, which included charts and instruments, had as its main item of interest the 15-inch equatorial telescope. Unfortunately the weather was overcast and not suitable for observing.

Members of the staff who assisted were: Seismology, Dr. E. A. Hodgson and Mr. W. W. Doxsee; Solar Physics, Dr. R. E. DeLury and Mr. J. L. O'Connor; Time Service, Messrs. D. B. Nugent, J. P. Henderson, R. J. McDiarmid, W. S. McClenahan, M. M. Thomson, and V. E. Hollinsworth; Magnetism, W. E. W. Jackson and R. G. Madill; Astrophysics, Miss Miriam S. Burland. The Library under J. H. L'Abbe, and the Photographic Division under G. H. A. Collins, were also open. Mr. J. D. H. Gauthier assisted in the men's cloak room, while Misses K. Nevins and H. Bowes assisted in the ladies'.

Refreshments were served by Morrison-Lamothe Bakery Ltd.

M. M. THOMSON, *Secretary.*



The Royal Astronomical Society of Canada

OFFICERS FOR 1942

Honorary President—THE HON. DUNCAN MCARTHUR, PH.D., Minister of Education for the Province of Ontario
President—FRANK S. HOGG, PH.D., Toronto
First Vice-President—MISS A. VIBERT DOUGLAS, PH.D., Kingston
Second Vice-President—A. E. JOHNS, PH.D., Hamilton
General Secretary—E. J. A. KENNEDY, 198 College St., Toronto
General Treasurer—J. H. HORNING, M.A., Toronto
Recorder—H. W. BARKER, Toronto
Librarian—P. M. MILLMAN, PH.D., Toronto
Curator—R. S. DUNCAN, Toronto
Council—D. S. AINSLIE, PH.D., Toronto; S. C. BROWN, Toronto; H. BOYD BRYDON, Victoria; J. W. CAMPBELL, PH.D., Edmonton; GEO. E. CAMPBELL, M.A., Hamilton; REV. W. G. COLGROVE, London; DEAN H. F. HALL, Montreal; E. A. HODGSON, PH.D., Ottawa; H. P. NEWTON, Vancouver; MISS F. S. PATTERSON, PH.D., Toronto; ANDREW THOMSON, PH.D., Toronto; L. A. H. WARREN, PH.D., Winnipeg; and Past Presidents—C. A. CHANT, LL.D.; A. T. DELURY, LL.D.; A. F. MILLER; J. R. COLLINS; W. E. W. JACKSON, M.A.; R. M. STEWART, M.A.; H. R. KINGSTON, PH.D.; R. K. YOUNG, PH.D.; L. GILCHRIST, PH.D.; R. E. DELURY, PH.D.; WM. FINDLAY, PH.D.; J. A. PEARCE, PH.D., and the presiding officer of each Centre.

TORONTO CENTRE

Honorary Chairman—C. A. CHANT, M.A., PH.D., LL.D.
Chairman—D. W. BEST, D.D. *Vice-Chairman*—MISS RUTH NORTHCOTT, M.A.
Secretary—TRACY D. WARING, 44 Rosepark Drive *Treasurer*—T. H. MASON
Curator—R. S. DUNCAN
Recorder—F. L. TROYER
Council—D. S. AINSLIE, PH.D.; L. GILCHRIST, PH.D.; J. F. HEARD, PH.D.; F. S. HOGG, PH.D.; J. H. HORNING, M.A.; P. M. MILLMAN, PH.D.; REV. C. H. SHORTT, M.A.; R. K. YOUNG, PH.D.; W. T. PATTERSON, R.O.; MISS E. M. FULLER, B.L.S.; H. DUNCALFE; and Past Chairmen—J. R. COLLINS, E. J. A. KENNEDY, and S. C. BROWN

OTTAWA CENTRE

Honorary President—MISS MIRIAM S. BURLAND *President*—F. W. MATLEY
First Vice-President—T. L. TANTON, PH.D. *Second Vice-President*—HOYES LLOYD
Secretary—MALCOLM M. THOMSON, Dominion Observatory
Treasurer—ANDREW C. STEEDMAN
Council—MRS. A. A. LOWES; H. M. BRADLEY; C. B. REILLY, K.C.; W. W. NICHOL, B.A.; R. J. MCDIARMID, PH.D.; and Past Presidents—JOHN MCLEISH, B.A.; A. H. MILLER, M.A.; R. G. MADILL, B.A.

HAMILTON CENTRE

Honorary President—W. T. GODDARD *President*—H. B. FOX
Secretary-Treasurer—J. R. GRAHAM, 64 Blake St. *Curator*—T. H. WINGHAM, B.A.Sc.
Council—F. H. BUTCHER, B.A.; T. M. NORTON, WM. FINDLAY, PH.D.; A. E. JOHNS, PH.D.; G. E. CAMPBELL, M.A.; W. S. MALLORY, M.A.; REV. E. F. MAUNSELL; MISS N. CORKE; MISS G. MASON

WINNIPEG CENTRE

Honorary President—MONSIGNOR T. W. MORTON *President*—L. W. KOSER
First Vice-President—V. C. JONES *Second Vice-President*—MISS O. A. ARMSTRONG
Treasurer—R. S. EVANS
Secretary—MISS M. E. WATTERSON, 612 Toronto General Trusts Bldg.
Council—R. D. COLQUETTE; L. J. CROCKER; C. A. E. HENSLEY; W. P. JOHNSON; G. P. MORSE; H. E. RITER; A. W. SMITH; A. V. THOMAS; PROF. L. A. H. WARREN; P. C. WATT

MONTREAL CENTRE

Honorary President—MGR. C. P. CHOQUETTE
President—D. P. GILLMOR, K.C. *Vice-President*—G. H. HALL
Secretary—H. F. HALL, Sir George Williams College, 1441 Drummond St.
Treasurer—F. J. DEKINDER
Council—O. A. FERRIER; DELISLE GARNEAU; A. M. DONNELLY; G. R. LIGHTHALL; E. P. MORGAN; E. RUSSELL PATERSON; DR. W. B. ROSS; DR. A. M. SHAW

VICTORIA CENTRE

Honorary President—GORDON SHAW *President*—R. M. PETRIE, PH.D.
First Vice-President— *Second Vice-President*—O. M. PRENTICE
Secretary-Treasurer—MISS M. OLIPHANT, 986 Wilmer St.
Recorder—ROBERT PETERS *Librarian*—MISS C. HAILSTONE
Director of Telescope Making Section—W. HOBDAY
Council—MISS V. LANGWORTHY; A. MCKELLAR, PH.D.; J. MOULSON; W. STILWELL, M.A.; MARK TRUEMAN; K. O. WRIGHT, PH.D.

LONDON CENTRE

Honorary President—DR. H. R. KINGSTON
Past President—REV. W. G. COLGROVE, M.A., B.D.
President—T. C. BENSON *Vice-President*—DR. G. R. MAGEE
Secretary-Treasurer—DR. RANDAL H. COLE, University of Western Ontario
Council—REV. M. E. CONRON; MRS. G. E. WOOD; J. W. BRYCE; E. H. MCKONE; D. M. HENNIGAR

VANCOUVER CENTRE

Honorary President—DR. J. A. PEARCE, Dominion Astrophysical Observatory
President—A. OUTRAM *Vice-President*—N. D. B. PHILLIPS
Recording Secretary—R. E. G. LANGTON, M.A.
Corresponding Secretary—H. D. SMITH, PH.D., Dominion Astrophysical Observatory
Treasurer—MRS. LAURA ANDERSON
Council—C. JORGENSON; MRS. C. A. ROGERS; F. R. STEWART; C. E. BASTIN; DR. RALPH HULL; F. G. BERTON; DR. VOLKOFF; M. A. MCGRATH

(Continued at bottom of next page)

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA
1890-1941

The Society was incorporated in 1890 under the name of The Astronomical and Physical Society of Toronto, and assumed its present name in 1903.

For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal, P.Q.; Ottawa, Toronto, Hamilton and London, Ontario.; Winnipeg, Man.; Edmonton, Alta.; Vancouver and Victoria, B.C. As well as about 700 members of these Canadian Centres, there are over 200 members not attached to any Centre, mostly resident in other nations, while some 300 additional institutions or persons are on the regular mailing list for our publications.

The Society publishes a monthly JOURNAL containing about 500 pages and a yearly OBSERVER'S HANDBOOK of 80 pages. Single copies of the JOURNAL or HANDBOOK are 25 cents, postpaid. In quantities of 10 or more copies, the price is 20 cents a copy.

Membership is open to anyone interested in astronomy. Annual dues, $2.00; life membership, $25.00. Publications are sent free to all members or may be subscribed for separately. Applications for membership or publications may be made to the General Secretary, 198 College St., Toronto.

The Society has for Sale:

Reprinted from the JOURNAL of the Royal Astronomical Society, 1936-1942.

The Physical State of the Upper Atmosphere, (revised 1941) by B. Haurwitz, 96 pages; Price 75 cents postpaid.

General Instructions for Meteor Observing, (revised 1940) by Peter M. Millman, 24 pages; Price 15 cents postpaid.

Two Inexpensive Drives for Small Telescopes, by H. Boyd Brydon, 12 pages; Price 10 cents postpaid.

A. H. Young's Simple Mounting for the 6-inch Reflector, by H. Boyd Brydon, 16 pages; Price 10 cents postpaid.

The Visual Photometry of Variable Stars, by H. Boyd Brydon, 64 pages; Price 50 cents postpaid.

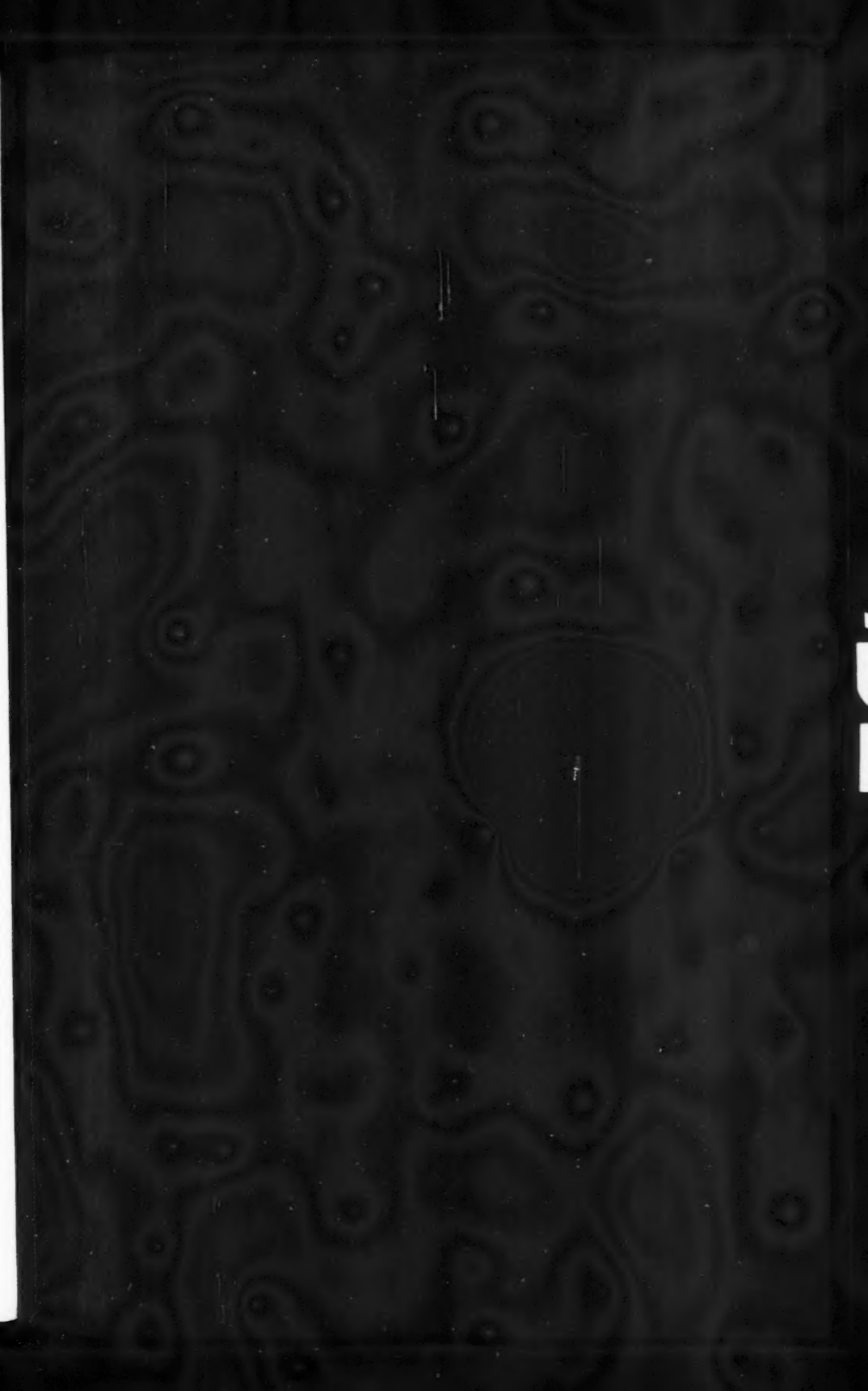
A Yoke Mounting for the Six-inch Telescope, by H. Boyd Brydon 8 pages; Price 10 cents postpaid.

In quantities of ten or more copies, a discount of 20 per cent will be allowed. Send Money Order to 198 College St., Toronto.

(Continued from previous page)

EDMONTON CENTRE

Honorary President—J. W. CAMPBELL, PH.D.
President—MRS. G. A. CLARKE *Vice-President*—J. A. MCLEAN
Secretary—E. H. GOWAN, PH.D., University of Alberta
Treasurer—E. N. HIGINBOTHAM *Librarian*—E. S. KEEPING, PH.D.
Council—H. R. LEAVER; C. G. WATES; G. W. ROBERTSON; A. COTSMAN; J. J. TUCK

QUEBEC CENTRE

Honorary President—ARTHUR SMITH, formerly Director of the Quebec Observatory
President—HENRI PAUL KOENIG, M.Sc. *Vice-President*—ALBERIC BOIVIN
Treasurer—LUCIEN POULIOT, C.A. *Secretary*—PAUL H. NADEAU, 275 rue St-Cyrille, Quebec
Assistant-Secretary—LIONEL GALLICHAN
Council—A. AMOS, C.I.; ABBE R. BENOIT; R. F. JOACHIM, F.E.C.; J. C. MAGNAN; M. L. CARRIER, C.I.; L. MASSE, D.Sc.; J. A. DUMONT; V. CARON, President Junior Section; G. H. MONTREUIL, Organizer Junior Section.